APPENDIX VII

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Materials Technology

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Testing and Examination of Pipe from Dixie Pipeline Company's 12-inch Hattiesburg, MS to Demopolis, AL Pipeline

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INTRODUCTION

As part of its pipeline integrity program, Enterprise Products Operating, LP inspected the Dixie Pipeline Company propane system with General Electric Company's "UltraScan CD" (USCD) in-line inspection tool. The pipe was 12-3/4-inch O.D. x 0.250-inch wall, electric-resistance welded, API specification 5LX Grade X52 manufactured in 1961. Twenty-one joints of pipe with inspection indications were subsequently removed from the pipeline for hydrostatic burst testing and examination. Prior to burst testing, some of the pipe was also inspected using phased-array ultrasonic testing (PAUT) and manual ultrasonic scanning (Manual).

Stork Metallurgical Consultants, Inc. (SMC) was contracted to have the pipe burst tested, examine the ruptured pipe visually, examine typical flaws found from examination of the fracture surface, determine the chemical composition, tensile properties and Charpy V-notch (CVN) impact properties of representative samples, have sections from an un-ruptured location with inspection indications from two joints fatigue tested, and examine specimens from a burst-tested and fatigue tested pipe in a scanning electron microscope (SEM) for evidence of flaw growth.

The 21 pipes were identified by Enterprise with a joint number, and were submitted in three groups of seven joints for testing and inspection. Each joint was also marked with the direction of flow for correlation with the inspection reports, which are referenced to the distance from the upstream girth weld.

SUMMARY OF FINDINGS

1. All of the 21 pipe joints ruptured in the burst test along the electric-resistance seam weld. The calculated hoop stress at failure based on the nominal dimensions ranged from 1.0 to 1.6 times the specified minimum yield strength.

2. Visual examination of the fracture surfaces along the hydrostatic test ruptures, and metallographic examination of specimens from fracture origins and other locations showed that nearly all the test failures originated at hook cracks.

3. Hook cracks were the most prominent flaws evident in the 21 joints, but there were also a large number of black spots and stitching along the weld.

4. The chemical composition and tensile properties of the first six pipes, which are considered representative of all 21 joints, met the requirements for Grade X52 of the API specification in force at the time of manufacture. The Charpy impact properties were normal for electric-resistance welded pipe manufactured in the 1960s.

5. Fatigue tests were run on sections of two joints removed from unfractured locations after the burst test, both of which contained inspection indications and magnetic particle indications of flaws. In the first test, the end cap leaked after 92,636 pressure cycles from 300 to 1440 psi, and the test was discontinued. In the second test, the pipe ruptured after 1,768 cycles.

6. The fatigue-test fracture originated at a hook crack on the inside surface that was approximately 40 inches long and 24 to 41 percent of the wall thickness deep. The hook crack was at a location where no inspection indications had been reported.

7. Visual and fractographic examinations of the fracture surface from the fatigue test showed a small area with fracture characteristics that were likely due to fatigue crack propagation.

8. Metallographic examination of magnetic particle indications at the locations of the reported inspection indications in the fatigue test sections showed contact marks from arcing of the welding electrode in the section from the first test, and a shallow hook crack down stream from the rupture in the second fatigue test. There was no evidence of fatigue crack extension from either defect.

HYDROSTATIC BURST TESTS

The burst tests were conducted by Hollico, Inc., and supervised by R. N. Greenslate of SMC. Hollico welded end caps to the pipe to be tested, filled it with water, and pressured it to failure using a positive displacement pump. As will be noted, for two tests the pump leaked and the pipe had to be de-pressured to repair the leak, which resulted in pressure cycles.

Figures 1 through 3 show the test number, joint number, burst pressure and pertinent dimensions of each burst joint. The hoop stress at burst ranged from 1.0 to 1.6 times the pressure corresponding to the specified minimum yield strength (SMYS), which is 2040 psi.

After testing, the fracture surfaces of each burst joint were coated with oil, and the pipe was sent to SMC for examination.

VISUAL AND METALLOGRAPHIC EXAMINATION

The pipe appeared to have been coated with coal tar enamel, and patches of coating remained on some of the joints. In addition, Joint Nos. 10737 and 5204 had been partially coated with a Polyguard RD-6 wrap. The coating was removed as necessary to examine the fracture surfaces, and paint-stencil marking was found on the outside surface of some joints indicating that they were manufactured by Lone Star Steel.

The rupture in each joint was photographed, and the fracture on one side of the rupture was cut out, cleaned with water and a detergent, examined and photographed. Each photograph includes a tape measure with the 0-inch mark at the upstream girth weld, from which the locations of flaws are referenced. In most of the fracture photographs, the outside surface of the pipe is at top, but in some of the first seven the outside surface is at bottom, as will be noted.

The fracture origin of most of the ruptures was evident by a bulge, chevron marks, or both, but in some cases the fracture origin was not obvious. The deepest flaw in each joint was measured and photographed; in most cases this flaw was at the fracture origin, but in a few it was not. The flaw depth measurements are only approximate, as it was sometimes difficult to determine the exact extent of a flaw. The wall thickness at the location of the deepest flaw was also measured to determine the flaw size as a percent of the actual wall thickness. The location of fracture origins and other flaws was also correlated to the locations of reported inspection indications using the summary report included in the APPENDIX, provided by Enterprise.

As part of the visual examination, we looked carefully for evidence of fatigue or other progressive crack growth. We found no beach marks or other characteristic indications of fatigue on any of the fractures from the burst tests.

Transverse sections were removed from each fracture for metallographic examination. The sections were taken from matching locations on each side of the fracture, and mounted together. The fractures did not always match well, due to small pieces breaking off one side of the fracture, post-failure damage to one side of the fracture, or a slight mismatch in the locations. For the first seven joints, sections were removed from representative flaws evident on the fracture surface for metallographic examination. Each metallographic specimen consisted of matching transverse sections through the flaw from each side of the rupture. The predominate flaws found on all the fracture surfaces were hook cracks and black spots. There was also some evidence of stitching. (*The nature and causes of these flaws is explained in the DISCUSSION section of this report.*) The fracture surfaces of the pipe from second and third groups of tests showed generally the same appearance as those from the first seven. Therefore, matching sections for metallographic examination were taken from only one location from each of the joints from Test Nos. 8 through 14, either from the failure origin or the deepest flaw.

The results of the examination of each joint follow.

Test No. 1 - Joint No. 6105

Figure 4 shows the rupture in Joint No. 6105, which extended from 22 feet, 4 inches to 28 feet, 10 inches. One inspection indication 1.4 inches long was reported by USCD within the length of the fracture, at 27 feet, 2 inches (27.2 feet).

The fracture initiated at a hook crack on the inside surface, which is shown in Figure 5. The hook crack was approximately three inches long, and at its deepest was 0.13 inch deep, which is 49 percent of the wall thickness. Other hook cracks were evident along the length of the fracture, separated by brittle fractures. The hook cracks were located near each surface and near midwall. One of the hook cracks, shown in Figure 6, was at the reported USCD indication. Figure 7 shows a typical hook crack upstream of the fracture origin.

Matching transverse sections were taken from the middle of the hook cracks shown in Figures 5 through 7, and prepared for metallographic examination. Figures 8 through 10 show the sections after polishing and etching with 3-percent nital, the etch typically used to examine the microstructure of carbon steel. To show details of the hook cracks better, we also etched some of the specimens with hot picric acid, which shows inclusions and fiber lines in steel. Figure 11 shows the hook crack at the inside surface at the fracture origin, shown in Figure 8, and Figure 12 shows the hook crack at the outside surface of the sections shown in Figure 9.

The specimens from this and most of the other joints examined metallographically showed no weld heat-affected zones, which is consistent with the Lone Star Steel paint-stencil markings. Unlike most other companies, Lone Star Steel heat treats the entire pipe body, which removes the heat-affected zones. At the time this pipe was likely manufactured, most electric-resistance welded pipe was not heat treated, although some manufacturers may have heat treated the weld area with induction coils.

Test No. 2 - Joint No. 2797

Joint No. 2797 was unusual in that it contained two ruptures separated by a two-inch un-ruptured length, as shown in Figures 13 and 14. One rupture extended from 6 feet to 9 feet, 1-1/2 inches, and the other from 9 feet, 3-1/2 inches to 23 feet, 2 inches. There was one USCD indication reported along the fracture length, between 12 feet, 4 inches to 15 feet, 8 inches.

No fracture origin was apparent on the fracture surfaces. The most prominent flaw was a hook crack on the outside surface that extended for several inches, and was deepest at 12 feet, 4 inches, as shown in Figure 15. (Note that in Figures 15 through 17 the outside surface is at bottom.) Other hook cracks were apparent along the length of the fracture as well as black spots. Many of the black spots were located in the length of the reported USCD indication, some of which are shown in Figures 16 and 17. The deepest flaw found along the fracture is indicated by the arrow in Figure 17; it was 0.19 inch deep or 79 percent of the measured wall thickness.

Figure 18 shows matching transverse sections from the hook crack, and Figure 19 shows the hook crack etched with hot picric acid, with an arrow indicating the weld line. Figure 20 shows the matching transverse sections from the black spot shown in Figure 17. The surfaces of the black spot were flat and straight, as shown in Figure 21, but beyond the black spot the surface was irregular, as shown in Figure 22. The flat surfaces along the black spot were never fused, whereas the irregular surfaces represent fractures of previously fused metal.

Test No. 3 - Joint No. 324

Figure 23 shows the rupture in Joint No. 324, which extended from 20 feet, 5 inches to 37 feet. There was one USCD indication 2-1/2 inches long reported along the fracture length, at 22 feet, 6 inches. The reported indication coincided with the apparent fracture origin at a hook crack on the outside surface, shown in Figure 24. In addition to a bulge, chevron patterns (not included in Figure 24) could be seen on each side of the hook crack, pointing to it as the failure origin. The maximum depth of the hook crack was approximately 0.10 inch, which was 37 percent of the measured wall thickness.

Other hook cracks were apparent along the length of the fracture, a typical example of which is shown in Figure 25.

Figures 26 and 27 show the matching transverse sections from the origin and the other hook crack, respectively, and Figure 28 shows the hook crack at the origin etched with hot picric acid.

Test No. 4 - Joint No. 6903

The rupture in Joint No. 6903, shown in Figure 29, had propagated across the upstream girth weld for two inches, and extended 14 feet, 7 inches beyond it to 14 feet, 5 inches. The fracture origin was not apparent, and the fracture in this joint was unusual in that there were no indications of hook cracks. Most of the fracture appeared brittle, with black spots present in groups along the length of the fracture, mostly on the outside surface.

There were nine inspection indications reported along the length of the fracture, all of which had been verified by either manual ultrasonic inspection or PAUT. As shown below, the reported indication lengths overlapped.

Inspection	Location of Indications Start	End
Manual	10 in	6 ft, 5 in
PAUT	10 in	1 ft, 11 in
Manual	6 ft,10 in	10 ft, 5 in
PAUT	8 ft, 0 in	10 ft, 0 in
PAUT	10 ft, 0 in	10 ft, 4 in
PAUT	10 ft, 5 in	11 ft, 0 in
PAUT	12 ft, 6 in	14 ft, 0 in
Manual	13 ft, 0 in	19 ft, 3 in
PAUT	16 ft, 0 in	18 ft, 0 in

The most continuous group of black spots was several inches long with the largest spots near the 2-foot location, as shown in Figure 30. (Note that the outside surface is at bottom in the fracture photographs for this joint.) The deepest flaw was at 2 feet, 1/4 inch, and was 0.13 inch deep, which is 51 percent of the measured wall thickness. At the other locations where inspection indications were reported, there were small black spots or no apparent flaws. Figure 31 shows three small black spots at the outside surface centered at 10 feet, one of the locations where indications were reported.

Matching transverse sections were taken from the locations indicated by arrows in Figures 29 and 30, and prepared for metallographic examination. Figures 32 and 33 show the sections after polishing and etching. The specimens showed broad heat-affected zones, typical of low-frequency electric-resistance welds, which indicated the pipe probably was not made by Lone Star Steel. At higher magnifications thin layers of apparently unfused metal could be seen along the surfaces of the black spot, as shown in Figures 34 and 35. Note also that the fiber lines on each side of the weld start out turned toward the outside surface, but are bent back toward the inside at the juncture of the abutting edges.

Test No. 5 - Joint No. 6106

The rupture in Joint No. 6106, shown in Figure 36, extended from 2 feet, 5 inches to 8 feet, 3 inches. There was a bulge near the middle of the rupture and slight post-rupture mechanical damage at the outside surface at the bulge. Two small flaws were apparent on the fracture surface in the bulged area at which the fracture may have initiated, which are shown in Figure 37. There was one reported inspection indication in the fracture length, at 4 feet, 6 inches, which appeared to be a hook crack and is shown in Figure 38. This was the deepest flaw in this joint, and was 0.15 inch deep, which is 55 percent of the measured wall thickness. At other locations the fracture surface was rough and irregular, with evidence of many small discontinuities.

Matching transverse sections were taken from one of the apparent flaws at the bulge, and from the hook crack at the reported inspection indication. Figures 39 and 40 show the sections from the flaws indicated by the arrows in Figure 37 and 38, respectively. Neither specimen showed a heat-affected zone, indicating they were from Lone Star Steel pipe. The sections at the bulge, Figure 39, did not match very well because of the mechanical damage on one side, white arrow. The fracture at this location appeared to have started along the weld line, black arrow, and broke at an angle across the base metal at the inside surface.

The part of the fracture in the specimen from the hook crack, Figure 40, was relatively straight, but at higher magnification much of the fracture was along the fiber lines next to the weld. However, the fiber lines were not as pronounced as were those in some of the other Lone Star Steel pipe.

<u>Test No. 6 - Joint No. 2796</u>

The rupture in Joint No. 2796 started at 46 feet, 8 inches, and extended to the upstream girth weld, as shown in Figure 41. There was a hook crack at a bulge that appeared to be the fracture origin, which is shown in Figure 42. (Note that the outside surface is at bottom in the fracture photographs for this pipe.) In addition to the hook crack at the origin, there were other hook cracks and a large number of black spots on the outside surface, some of which are shown in Figure 43. There were no inspection indications reported within the fracture length. The depth of the hook crack was 0.09 inch or 32 percent of the wall thickness, which was 0.264 inch. The deepest flaw, at one of the black spots, was 0.12 inch deep, or 44 percent of the wall thickness, which was 0.275 inch.

Figures 44 and 45 show matching transverse sections from the failure origin and one of the black spots, respectively. When etched with hot picric acid, the hook crack at the origin appeared similar to the hook crack shown in Figure 12. In contrast, the specimens from the black spot showed flat, smooth surfaces along the weld line at the black spot, which was on the outside surface, that became more irregular as the fracture deviated away from the weld line. Figure 46 shows the jagged fracture just above the black spot, and Figure 47 shows the flat portion of the black spot at the inside surface. The smooth surfaces were never fused.

Test No. 7 - Joint No. 6102

The rupture in Joint No. 6102, shown in Figure 48, was 7 feet, 9 inches long and extended to within one inch of the downstream girth weld. The fracture surface was, for the most part, flat and brittle with small black spots and small hook cracks scattered along the length. The deepest flaw was at a black spot at 43 feet, 5 inches, shown in Figure 49 with other black spots nearby, and was 54 percent of the wall thickness deep. There were two USCD features reported within the fracture length, one 25 to 40 percent of the wall thickness deep at 39 feet, 1 inch, and one less than 12.5 percent of the wall thickness deep at 44 feet, 2 inches. As shown in Figure 50, no defect was apparent at 39 feet, 1 inch; the flat, brittle fracture at this location is typical of most of the fracture surface. Figure 51 shows shallow hook cracks at 44 feet, 2 inches, where the shallow USCD indication was reported.

Matching transverse sections were taken from the black spot at the 43 feet, 5 inch mark in Figure 49, and across the hook crack near the 44 feet, 2 inch mark in Figure 51. Figures 52 and 53 show the sections after polishing and etching. Note the heat-affected zones that show this joint either was not manufactured by Lone Star Steel, or was not full-body normalized after welding. The fracture along the black spot was straight and flat, as shown in Figure 54. Note that the fibers on each side of the fracture are reverse bent so that they turn back down at the weld instead of turning toward the outside surface. A thin layer of scale can be seen on the fracture at left, and a thin layer of decarburized (light-etching) metal can be seen on the fracture at right.

Test No. 8 - Joint No. 2753

The rupture in Joint No. 2753, shown in Figure 55 was 10 feet, 9 inches long and opened less than an inch at the widest point. The fracture surfaces were rough and irregular for most of the length, with long hook cracks apparent at several locations. The most likely failure origin was at a long hook crack at the outside surface near the middle of the rupture where a 4.9-inch long USCD indication was reported. Figure 56 shows the hook crack that extended approximately from 32 feet to 32 feet, 8 inches; the USCD indication was reported at 32 feet, 4 inches

(32.32 feet). The depth of the flaw at the origin was 59 percent of the wall thickness. Figures 57 and 58 show another representative location.

Matching transverse sections were taken from the middle of the hook crack shown in Figure 55 and prepared for metallographic examination. Figure 59 shows the specimens after polishing and etching. The jagged edges were due to parting along the fiber lines; the arrow indicates the weld line.

Test No. 9 - Joint No. 4013

Joint No. 4013, shown in Figure 60, ruptured for a length of 4 feet, 11 inches. The apparent origin was at a hook crack located at a bulge near the middle of the rupture, centered at 44 feet, 8 inches, as shown in Figure 61. The depth of the hook crack was 44 percent of the wall thickness. The rest of the fracture was mostly flat and brittle, with apparent flaws on the inside surface at a few locations. A USCD indication was reported at 45 feet, 7 inches (45.6 feet). As shown in Figure 62, there appeared to be a large hook crack or other flaw at the inside surface at that location.

Matching transverse sections were taken from the middle of the area shown in Figure 61, and are shown in Figure 63 after polishing and etching. The flaw at the inside surface was adjacent to the weld line, and examination at higher magnification showed that it was along the down-turned fiber lines, hence was a hook crack

Test No. 10 - Joint No. 6418

Joint No. 6418, shown in Figure 64 ruptured near one end of the joint, for a length of 4 feet, 8 inches. The apparent fracture origin was at a bulge at 4 feet, 3 inches, shown in Figure 65. There appeared to be flaws at both the inside and outside surfaces, the combined depths of which were approximately 60 percent of the wall thickness. There were no inspection indications reported in the fracture length. The rest of the fracture was mostly flat and brittle, with hook cracks apparent at a few locations. Figure 66 shows a location with a long hook crack near midwall.

Matching transverse sections were taken from the failure origin and prepared for metallographic examination. Figure 67 shows the sections after polishing and etching. A large hook crack was apparent at the outside surface.

Test No. 11 - Joint No. 10737

Joint No. 10737 been wrapped with Polyguard and a strip of the coating had to be removed to examine the rupture. Figure 68 shows the pipe after the strip was removed from each side of the rupture, which was 8 feet, 1 inch long. The fracture surface contained a large number of hook cracks along the length of the rupture, with brittle fractures in between. The failure origin was not apparent but likely was at one of the hook cracks. Manual and PAUT inspection indications were reported at 5 feet, 6 feet, 5 inches (6.4 feet), 6 feet, 7 inches (6.6 feet) and 8 feet. The indication at 5 feet was reported to be 10.93 inches long and 36 percent of the wall thickness deep. Our examination showed the deepest flaw, 50 percent of the wall thickness, to be at 5 feet, 8.5 inches, shown in Figure 69. The fractures at the other two reported indications contained large hook cracks, as shown in Figures 70 and 71.

Matching transverse sections were taken from the fracture shown in Figure 69 and prepared for metallographic examination. As shown in Figure 72, there was a large hook crack at the inside surface and smaller hook cracks toward the outside.

Test No. 12 - Joint No. 7757

Joint No. 7757, shown in Figure 73, ruptured for a length of 6 feet, 1 inch. The apparent failure origin was at a hook crack centered 42 feet, 5 inches, shown in Figure 74. The depth of the hook crack was 24 percent of the wall thickness. The rest of the fracture was flat and brittle, with some stitching and small black spots. Figure 75 shows an area with black spots at the inside surface and evidence of stitching on the outside surface.

Matching transverse sections were taken from the fracture origin and prepared for metallographic examination. Figure 76 shows the sections after polishing and etching. The fiber lines were not as apparent as in some of the other sections, but examination at higher magnifications showed separation along the fiber lines in the steel.

Test No. 13 - Joint No. 3897

Joint No. 3897, shown in Figure 77, fractured for a length of 4 feet, 10 inches. The apparent fracture origin was at a hook crack at a bulge at the middle of the rupture.

The hook crack, shown in Figure 78 was on the outside surface, and its depth was 22 percent of the wall thickness. The rest of the fracture was mostly brittle, with some long hook cracks at the inside and outside surfaces. Figure 79 shows a typical area with brittle fracture and hook cracks.

Matching transverse sections were taken from the hook crack at the fracture origin and prepared for metallographic examination. Figure 80 shows the sections after polishing and etching, with an arrow indicating the weld line. The fracture at the outside surface was along the fiber lines, but was partially along the weld line and partially across fiber lines for most of the fracture.

Test No. 14 - Joint No. 5204

Joint No. 5204, which had also been partially wrapped with Polyguard, is shown in Figure 81 after the wrap was removed from the fracture. The fracture was 6 feet, 11 inches long, there was no clear fracture origin, but several long hook cracks were apparent along the length of the rupture. The deepest hook crack, shown in Figure 82, was 50 percent of the wall thickness deep, several inches long, and was contiguous with a PAUT indication 3.4-inches long reported at 8 feet, 11 inches (8.9 feet).

Matching transverse sections were taken from the deepest part of the hook crack and prepared for metallographic examination. As shown in Figure 83, the fracture at the outside surface was along the fiber lines, while part of the fracture near midwall was along the weld line.

Test No.15 - Joint No. 3645

Joint No. 3645, shown in Figure 84, fractured for a length of 5 feet, 1 inch, with an apparent origin at a hook crack on the outside surface at a bulge near the middle of the rupture. The hook crack, shown in Figure 85 was centered at 31 feet, 8 inches and had a depth of 28 percent of the wall thickness. A USCD indication was reported at 31 feet, 6 inches (31.53 feet), which presumably is the same flaw. There were several long hooks cracks along the fracture separated by brittle fractures. The deepest flaw, at 31 feet, 3 inches, was a hook crack at the outside surface, shown in Figure 86, the depth of which was 42 percent of the wall thickness.

Matching transverse sections were taken from the fracture origin and prepared for metallographic examination. Figure 87 shows the specimens after polishing and etching. Near each surface, the pipe separated along the upturned and downturned flow lines, but toward midwall was across the fiber lines.

Test No. 16 - Joint No. 332

Joint No. 332, shown in Figure 88, fractured for a length of 10 feet, 9 inches. Unlike the other failures, there was no prominent defect at the fracture origin, but chevron patterns pointed to a location near 13 feet, 10 inches as the origin. Figure 89 shows the chevrons pointing to the failure origin, and Figure 90 is a closer view of the origin. Neither the type nor depth of the flaw at the origin was readily apparent. Most of the fracture surface was flat and brittle, with only a few hook cracks evident. The deepest flaw was a hook crack at the outside surface that penetrated 46 percent of the wall thickness. There were no inspection indications reported along the length of the rupture.

Matching transverse sections were taken from the fracture origin and prepared for metallographic examination. Figure 91 shows the specimens after polishing and etching. A broad heat-affected zone was evident which, because of its width, appeared to be from a localized post-weld heat treatment. At higher magnifications, the pipe was seen to have fractured along the fiber lines for most of the wall thickness, including the flat area at the outside surface, which is indicative of hook cracks.

Test No. 17 - Joint No. 6005

Joint No. 6005, shown in Figure 92, ruptured for a length of 6 feet, 3 inches. The apparent fracture origin was at a hook crack on the outside surface at a bulge near the center of the rupture centered at 53 feet, 5 inches, shown in Figure 93. The depth of the hook crack was 34 percent of the wall thickness. Other hook cracks were apparent along the length of the rupture, as well as areas of smooth brittle fracture and areas of multi-layered brittle fracture. A USCD inspection indication was reported at 50 feet, 10 inches (50.865 feet) but no significant flaw was seen on the fracture at that location.

Matching transverse sections were taken from the fracture origin and prepared for metallographic examination. As shown in Figure 94, hook cracks were apparent across most of the wall thickness.

Test No. 18 - Joint No. 7634

The rupture in Joint No. 7634, shown in Figure 95, was the shortest of all the ruptures and stopped at one end at the upstream girth weld. There was what appeared to be a long deep hook crack centered at 8 inches, shown in Figure 96, that appeared to be the fracture origin. At its deepest, the hook crack was 48 percent of the wall thickness. Most of the rest of the fracture surface was brittle in appearance with other, smaller, hook cracks and some stitching.

Matching transverse sections were taken from the fracture origin and prepared for metallographic examination. As shown in Figure 97, there was a large slanted separation at the inside surface that appeared to be a hook crack, but was further from the weld line than most hook cracks. Examination at higher magnification showed that the separation was along the fiber lines, and was a hook crack.

Test No. 19 - Joint No. 2405

Figure 98 shows the rupture in Joint No. 2405, which was 7 feet, 10 inches long. The fracture surfaces were rough and irregular for most of the length, with indications of hook cracks and multi-layered separations. The most likely failure origin was at the deepest flaw, a hook crack at the outside surface shown in Figure 99, the depth of which was 48 percent of the wall thickness. There was a 20.6-inch long USCD indication reported at 49 feet, 3 inches (49.24 feet) that appeared to be a hook crack at the outside surface, part of which is shown in Figure 100.

Matching transverse sections were taken from the hook crack shown in Figure 99, and prepared for metallographic examination. As shown in Figure 101, the fracture was mostly along fiber lines.

Test No. 20 - Joint No. 386

Figure 102 shows the rupture in Joint No. 386, which was 7 feet, 3 inches long. The fracture was rough and irregular, with several hook cracks evident. The likely failure origin was at a hook crack, shown in Figure 103, which was at a bulge along the fracture. This hook crack was the deepest flaw, with a depth of 35 percent of the wall thickness. There were no inspection indications reported along the fracture length.

Matching transverse sections were taken from the hook crack shown in Figure 103, and prepared for metallographic examination. As shown in figure 104, the fractures were relatively straight, and at higher magnification could be seen to follow the fiber lines across most of the wall thickness. The outside surface was mechanically damaged,

Test No. 21 - Joint No. 8769

Figure 105 shows the rupture in Joint No. 8769, which was 4 feet long. The fracture surface was rough and irregular with multilayered fractures, hook cracks and black spots. There were no inspection indications reported along the length of the fracture. The failure origin was not apparent, but there were a number of black spots and hook cracks along the fracture length. Figure 106 shows a hook crack, multilayered fracture and black spots at a bulge near the middle of the rupture. The deepest flaw was a narrow black spot just beyond the bulge, shown in Figure 107, that penetrated almost completely across the wall thickness. A broader black spot nearby had a depth of 76 percent of the wall thickness.

Matching transverse sections were taken from the black spot indicated by the arrow at left in Figure 107. As shown in Figure 108, the fracture was straight and flat along the black spot, with a rough irregular fracture at the inside surface.

SCANNING ELECTRON MICROSCOPY

As part of the visual examination of the fracture surfaces, we looked for evidence of fatigue or other progressive crack growth, and found none. We were also asked to examine an appropriate fracture in a scanning electron microscope (SEM)for evidence of fatigue that might not have been apparent in the visual examination. The fracture from Joint No. 332 (Test No. 16) was chosen for SEM examination because the pipe was subjected to three pressure cycles due to pump malfunctions, and experienced a pressure reversal, that is, it ruptured at a lower pressure than a pressure that previously had not caused rupture. Moreover, as discussed previously, chevron patterns indicated a precise fracture origin at a small hook crack at the outside surface.

A specimen was removed from the fracture origin at 13 feet, 10 inches, which is shown in Figure 90, cleaned and placed in the SEM (the SEM examination was completed before the metallographic examination). Figure 109 shows the fracture origin with the outside surface at top. There were hook cracks at the outside and inside surfaces. The fracture along the hook cracks was partly dimpled with some inclusions and other areas with no clear fracture mode. Figure 110 shows the area in the box at top at higher magnification. The large plateau just below the hook crack was all cleavage, as represented by the area in the lower box, shown at higher magnification in Figure 111. Below this area, the fracture was mostly cleavage except for the small hook crack at the inside surface.

We also examined the areas on each side of the fracture origin. Figure 112 shows the area just to the right of the origin, with boxes indicating locations shown at higher magnifications in subsequent figures. The hook cracks at the outside, top box, and inside, bottom box, surfaces are shown in Figures 113 and 114, respectively. The hook crack at top had finer features than the one at bottom, part of which appeared to be covered with a scale. There appeared to have been more inclusions along the hook crack at bottom. Just below the origin, the fracture surface was layered with small longitudinal bands, the appearance of which is often described as "woody". Figures 115 and 116 show the woody fracture at the second box from the top at two magnifications. At the location of the third box from the top, the fracture changed from woody to cleavage, as shown in Figures 117 and 118. Cleavage fracture extended all the way to the hook crack at the inside surface.

The fracture to the left of the origin had similar characteristics. We found no beach marks, striations or other evidence of fatigue at any of the three locations.

CHEMICAL ANALYSES AND MECHANICAL PROPERTIES

The chemical composition, tensile properties and Charpy V-notch impact properties were determined for the first six pipe joints. The chemical composition was determined by optical emission spectroscopy, and the tensile properties were determined using transverse strip specimens from the base metal and across the seam weld. The results, shown in Tables 1 and 2, met the requirements of the Ninth Edition of API Specification 5LX, which was published in February, 1960, and was in effect in 1961. Table 3 shows the results of the Charpy impact tests, which were made using 1/2-size (10-mm x 5-mm) transverse specimens tested at 70°F. There were no impact requirements in API 5LX in1961.

Based on the fact that the six joints were from different locations along the pipeline and had similar properties, it was not deemed necessary to determine the chemical composition or mechanical properties of the other pipe joints.

FATIGUE TESTS

Sections from un-fractured lengths of Joint Nos. 6418 and 10737 were selected for fatigue testing. Each section contained PAUT and manual inspection indications, which had been verified by magnetic particle inspection. The indications were reported as follows:

Joint	Inspection Type	Location, ft[1]	Length, in	Depth, % Wall	Radial Position	Type
6418	Manual	41.0	54	36.8	External	Crack
6418	PAUT	41.4	6.45	36.0	External	Crack
6418	PAUT	44.0	18.90	36.0	External	Crack
10737	Manual	25.2	6.75	38.0	Multiple[2]	LOF[3]
10737	Manual	39.9	18.00	34.4	Multiple	LOF
10737	PAUT	42.0	24.00	38.0	External	LOF

1. Distance from Upstream Girth Weld
2. Internal, external and midwall
3. Lack of fusion

The locations shown above were re-inspected with magnetic particles. On Joint No. 6418 we found a pattern of small, curved discontinuous indications extending from 36 feet, 10 inches to 46 feet, 7 inches. Figure 119 shows typical indications, which appeared to be contact marks caused by arcing between the welding electrode and the pipe. Metallographic examination after fatigue testing confirmed that they were contact marks; see Figure 120.

On Joint No. 10737, there was a similar discontinuous line of straight indications at the three locations. Figure 121 shows typical indications, and Figures 122 and 123 show matching transverse sections across one of the indications, which was a small hook crack.

The section for fatigue testing from Joint No. 6418 was taken from 36 feet, 10 inches to 51 feet, 2 inches and included the locations of all the reported PAUT indications listed above. The section for fatigue testing from Joint No. 10737 was taken from 38 feet, 6 inches to 58 feet, 7 inches, and included the last two locations of Manual and PAUT indications listed above.

The test sections were shipped to Stress Engineering Services (SES) for fatigue testing. End caps were welded to each of the test sections, which were then pressured one at a time with water cycled from 300 to 1,440 psi. Joint No. 6418 was tested first, and after 92,636 pressure cycles one of the end caps cracked and leaked. Joint No. 10737 was then tested, and ruptured after 1,768 pressure cycles. It was decided not to continue the test of Joint No. 6418.

Examination of Joint No. 6418

The outside surface of Joint No. 6418 was re-inspected with magnetic particles after the fatigue test. Contact-marks similar to those shown in Figure 119 were found at the locations of reported inspection indications. Figure 124 shows the heaviest and most continuous indications. A section for metallographic examination was taken across the indications at the middle of the area shown in Figure 124, and is shown in Figure 125 after polishing and etching. The inspection indications were caused by a seam (black arrows), but there also was a contact mark at the outside surface At higher magnification, entrapped copper from the electrode could be seen at the contact mark. There was no evidence of fatigue crack extension from the seam or contact mark.

Examination of Joint No. 10737

The fatigue-test rupture in Joint No. 10737 was 3 feet, 8 inches long, and extended from 46 feet, 8 inches to 50 feet, 4 inches, which was not a location with reported inspection indications. Figures 126 through 128 (provided by SES) show the fracture immediately after testing. Note that the downstream end is at left in Figures 126 through 128. The appearance of the fracture surface indicated that the failure started at large hook cracks.

Figure 129 shows the rupture with the downstream end at right, and a tape measure showing the distance from the upstream girth weld. The diameter at the middle of the rupture, measured with a pi tape, was 12.76 inches, which indicated no expansion prior to fracture.

We cut the fractures from the pipe, cleaned them and examined them visually. The failure appeared to have originated near the middle of the rupture at a large hook crack on the inside surface that was continuous for almost the full length of the rupture. Figures 130 and 131 show part of the hook crack near the middle of the rupture, and Figure 132 shows the hook crack near the downstream end. The hook crack was 0.07 inch deep, or 24 percent of the wall thickness near the middle of the rupture, and 0.11 inch deep, or 41 percent of the wall thickness at the location shown in Figure 132. The fracture appearance toward the outside surface was indicative of smaller hook cracks.

We examined the fracture surface carefully for evidence of fatigue. Two areas of bright, flat fractures with possible fatigue indications were found and examined in an SEM. Bright surfaces are indicative of relatively fresh fractures, as opposed to dark areas that represent prior flaws. The first area was found to be all cleavage fracture. The second area showed a narrow band within the area of bright fracture with steps across the fracture surface that were suggestive of fatigue. Figures 133 and 134 show part of the second area, which was centered at 48 feet, 9 inches, with arrows indicating the bright band with possible fatigue markings. Figure 135 shows the fracture at higher magnification; the fresh fracture does not appear bright because the micrograph was taken in the SEM. The longitudinal lines within the band indicated by the arrows were not seen elsewhere on the fracture.

We examined the fracture within the possible fatigue area, above it and below it at various magnifications up to 2,000X. Figure 136 is a low-magnification view showing the possible fatigue area (F) at bottom, the hook crack (H) at top, with overload fracture between the two. Part of the overload fracture was tearing (T) by microvoid coalescence, and part was cleavage (C). Figures 137 and 138 show the fracture at two locations within the area indicated by the arrows in Figure 135. At each location examination at high magnification showed fine parallel markings like those caused by fatigue. The fracture at these locations was not characteristic of cleavage or microvoid coalescence, which are shown in Figures 139 and 140. Although the markings in the suspected fatigue area were not as clear as fatigue markings often found, their presence and the absence of microvoid coalescence or cleavage indicates likely fatigue crack propagation.

The appearance of the hook crack at top in Figure 136 was similar to that of the hook crack shown in Figure 114.

Matching transverse sections were taken from each side of the fracture at the location shown in Figure 134, and prepared for metallographic examination. Figure 141 show the sections after polishing and etching, with a large hook crack evident at the inside surface, smaller hook cracks at the outside surface and flat fracture in between. Figures142 through 144 show the large hook crack at the inside surface at higher magnifications. There was scale along the surface of the hook crack, indicating it originated during manufacture of the pipe. As shown in Figure 143, the fiber lines on one side of the weld were very irregular, which is indicative of offset skelp edges during manufacture.

Figure 145 shows the fracture near midwall, which includes the flat area that was examined in the SEM, arrow, and Figure 146 shows the flat area at higher magnification. The flat, straight fracture is consistent with, but not necessarily indicative of, fatigue.

The reported Manual and PAUT inspection indications were downstream of the rupture, and were covered with Polyguard wrap. The wrap was removed and the weld at those locations was inspected with magnetic particles. We found a number of straight, discontinuous indications similar to those shown in Figure 111. Figure147 shows a location with the heaviest magnetic particle build up, which is shown in closer view in Figure 148. A section for metallographic examination was taken from the location of heaviest particle build-up. As shown in Figure 149, the indication was caused by a hook crack that was approximately 0.02 inch deep. There was no evidence of fatigue crack extension from the hook crack.

DISCUSSION

The examination showed that most of the 21 pipe joints contained numerous flaws along the electric-resistance seam weld, predominately hook cracks, but also a number of black spots and stitching. Hook cracks result from the properties of the skelp from which the pipe is made, and how it is formed, whereas black spots and stitching are related to the welding process. Skelp is produced by the hot reduction of a slab between rolls into a long, thin strip. The hot reduction creates a directionality in the skelp due to segregation of elements and nonmetallic inclusions along planes that are flattened in the direction of rolling, as illustrated schematically in Figure 150. The strength and ductility are highest in the x and y directions, and lowest in the z direction. Electric-resistance welded pipe is manufactured by forming skelp progressively into a cylindrical shape, passing an electric current across the converging edges, and forcing the abutting edges together, as illustrated in Figure 151. For low frequency electric-resistance welding, the current was introduced by copper electrode wheels on each side of the weld. Because heating of the skelp edges oxidized the surface layers, the edges had to be brought together with sufficient force to extrude all the oxidized metal, called "flash", and form a pressure weld in sound metal. The flash was then trimmed from each surface. Insufficient force could lead to a weak weld or to entrapped flash along the weld line. Pre-arcing of the abutting edges prior to convergence could cause oxidation that prevented subsequent fusion and lead to un-welded "black spots". Arcing between the welding electrode and the outside surface of the pipe caused contact marks, which normally were less serious than other types of flaws.

Low-frequency electric-resistance welded pipe typically utilized alternating current of 60 to 360 hertz. With alternating current there is a heat peak each half cycle. Depending on the speed at which the skelp moves through the mill, the metal between peaks may not be heated to the optimum welding temperature, resulting in weaker welds at regular intervals. The intermittent weld condition appears as slanted lines across a fractured weld, and is referred to as "stitching".

One of the most common flaws in older electric-resistance welded pipe, and the most common found in the 21 test joints, are hook cracks. When the abutting edges are brought together, the fiber lines in the skelp are bent toward the outside and inside surfaces, as illustrated in Figure 152. The change in direction at the weld creates a weak plane, similar to the z direction in the skelp. The properties in this plane depend on the amount of segregation and, particularly, the number and size of nonmetallic inclusions in the steel. Depending on the properties of the skelp, how the pipe is formed, how the skelp edges are prepared and other factors, separations may develop along the up-turned and down-turned fibers during manufacture. In addition, separations may develop along the fiber lines from the stress caused by internal pressure. In either case, the separations are called hook cracks. Scale from the heat of welding can sometimes be found on the surface of hook cracks, which shows they formed during manufacture. Often, however, no scale is apparent, and it is not clear whether the hook crack formed during manufacture or subsequently due to stress across weak fiber lines.

Hook cracks are identifiable on fracture surfaces because of the curved separations. Figure 153 illustrates a fracture surface with hook cracks across the wall, and Figure 154 illustrates a fracture with partial hook cracks.

Despite the size and frequency of hook cracks and other flaws, the failure pressures in the burst test were all at or above the pressure equivalent to the SMYS. The relatively high failure pressures were likely due in part to the fact that the actual yield strength in most cases was well above the SMYS. Nevertheless, the tests demonstrated that even pipe with large flaws can withstand pressures in excess of the maximum allowable operating pressure. In addition, the fatigue test of the section from Joint No. 6418 showed that pipe with reported inspection indications of significant size may have very high fatigue resistance. Moreover, the test on the section from Joint No. 10747 showed a significant degree of fatigue resistance despite the presence of a long, deep hook crack.

The fatigue tests served a dual purpose: to evaluate the fatigue resistance of the pipe, and to determine the observable characteristics of fatigue crack growth in the pipe. Fatigue frequently is evident visually by beach marks that form as a crack arrests and re-initiates, in response to changing stresses. The beach marks emanate from the fracture origin and typically continue to the point that the remaining cross section fails by overload. In the absence of beach marks, examination at high magnification will often show striations, which form as the crack advances with each stress cycle. The SEM examination of the fracture from the fatigue test of the section from Joint No. 10747 did exhibit markings that most likely were striations. The striations were not as clear as we often find on fatigue fractures, but areas where they were found did not exhibit characteristics of cleavage or of microvoid coalescence, hence, most likely were indicative of fatigue.

We found no beach marks or other visual evidence of fatigue on the fracture surfaces of the burst-test ruptures. Moreover, we found no areas similar to the area with likely fatigue markings on the fatigue-test fracture. The absence of beach marks or striations does not mean that the burst test failure did not involve flaw growth. Clearly all the failures initiated at a flaw which “grew” to rupture. Whether or not the growth was instantaneous or progressive is not clear, except in the case of Joint No. 332, the pressure reversal shows that there must have been some stable crack growth, that is, growth at a constant pressure that arrested short of rupture. Given the nature of hook cracks and other flaws in electric-resistance welded pipe, it seems reasonable that rupture by cleavage or microvoid coalescence of ligaments between inclusions or between adjacent flaws could cause small flaws to grow to critical size. This type of growth is different from classical fatigue, in which cyclic stresses causes microcracks to initiate at steps along slip planes.

Chemical Analyses

	324	2796	2797	6102	6105	6106	6903	Grade X52
Carbon, %	0.29	0.22	0.27	0.22	0.28	0.24	0.26	0.35 max.
Manganese, %	1.28	1.22	1.21	1.26	1.28	1.23	1.24	1.40 max.
Phosphorus, %	0.035	0.029	0.026	0.028	0.035	0.033	0.031	0.05 max.
Sulfur, %	0.024	0.021	0.019	0.022	0.029	0.018	0.017	0.06 max.
Silicon, %	0.05	0.04	0.04	0.05	0.05	0.04	0.04	*
Chromium, %	0.04	0.04	0.03	0.03	0.03	0.03	0.06	*
Nickel, %	0.07	0.09	0.09	0.06	0.06	0.06	0.08	*
Molybdenum, %	0.01	0.01	0.01	<0.01	<0.01	<0.01	0.01	*
Copper, %	0.42	0.39	0.39	0.39	0.40	0.41	0.39	*

*Not specified

Table 1

Results of the chemical analyses.

Tension Tests

Pipe Body	324	2796	2797	6102	6105	6106	6903	Grade X52
Yield Strength, ksi	67.7	65.4	63.8	58.8	67.0	64.1	63.3	52.0 min.
Tensile Strength, ksi	91.5	93.7	89.0	82.4	84.4	83.9	87.7	66.0 min.
Elong., % in 2"	28.2	21.8	28.3	28.6	28.7	31.1	29.5	22.0 min.
Weld								
Tensile Strength, ksi	90.2	86.3	83.3	86.3	90.1	85.1	80.4	66.0 min.

Table 2

Results of the tension tests.

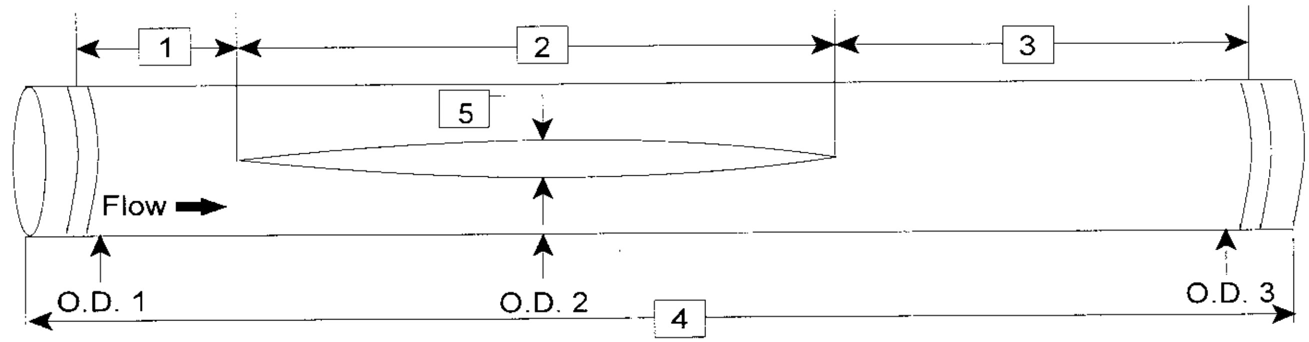
Charpy V-Notch Impact Tests*

Pipe Body	324	2796	2797	6102	6105	6106	6903
Energy, ft-lbs	9, 8, 10.5	11, 12.5, 12	11.5, 11.5, 10	12, 13, 12	10, 9, 10	15, 15, 15.5	13, 15.5, 14.5
Percent Shear	70, 70, 70	70, 85, 70	55, 50, 45	100, 100, 100	70, 75, 80	80, 70, 80	75, 90, 85
Weld							
Energy, ft-lbs	8, 8, 6.5	6, 9, 8	4, 4.5, 7.5	7, 11, 7.5	15, 14.5, 10.5	15, 14.5, 10.5	3.5, 5, 5
Percent Shear	45, 40, 50	70, 85, 70	25, 35, 35	45, 40, 45	80, 80, 80	80, 80, 80	5, 10, 10

*1/2-size transverse specimens tested at 70°F

Table 3

Results of the Charpy impact tests.

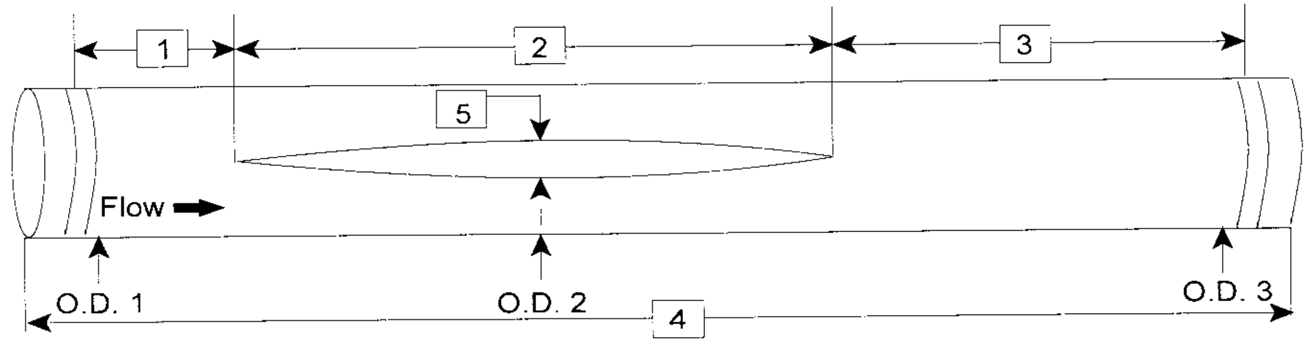


			Dimensions[1]					O.D., in		
Test No.	Joint No.	Pressure, psi	1	2	3	4	5	1	2	3
8	2753	2250	27' 4"	10' 9"	18' 9"	56' 10"	7/8"	12.75	12.77	12.73
9	4013	2790	42' 2"	4' 11"	11' 8"	58' 9"	2-3/4"	12.74	12.76	12.74
10	6418	3025[3]	1' 10"	4' 8"	48' 6"	55'	3-3/8"	12.77	12.79	12.78
11	10737	2250	-1"	18' 1"	40' 1"	58' 2"	7/16"	12.76	12.78	12.78
12	7757	2775	39' 2"	6' 1"	0"	45' 4"	1-5/8"	12.76	12.79	12.78
13	3897	2775	6' 1"	4' 10"	47' 10"	58' 10"	3-1/16"	12.76	12.76	12.76
14	5204	2055	3' 11"	6' 11"	36' 2"	47'	3/4"	12.73	Note 2	Note 2

Notes: 1. To the nearest inch unless otherwise shown.
2. Covered with Polyguard, did not measure.
3. Third pressure cycle due to pump malfunction. Previous 2950, 2350 psi.

Figure 2

Failure pressures and dimensions for the second seven burst tests.

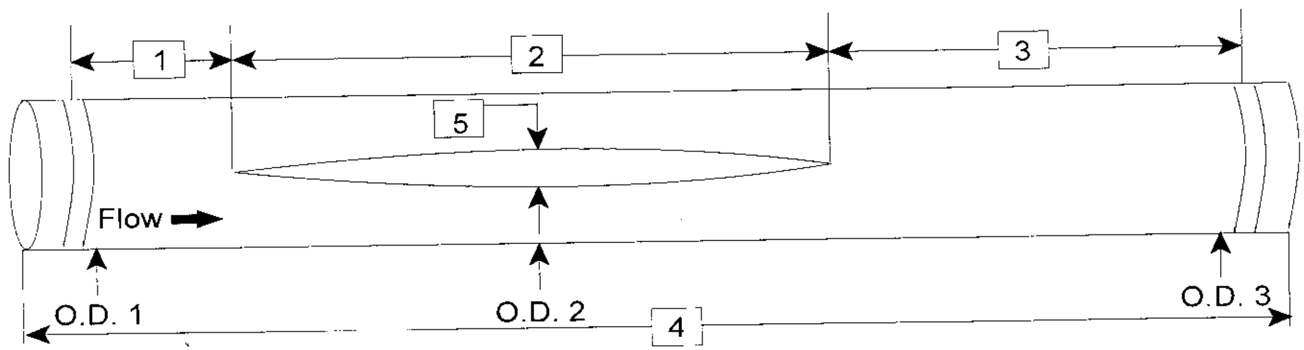


			Dimensions[1]					O.D., in		
Test No.	Joint No.	Pressure, psi	1	2	3	4	5	1	2	3
1	6105	2880	22'4"	6'6"	27'4"	56'1"	3-3/32"	12.75	12.79	12.75
2[2]	2797	2875	6'	3'1"	48'8"	57'10"	7/32"	12.74	12.79	12.74
2A[2]	2797	2875	9'4"	13'10"	48'6"	57'10"	1-1/4"	12.74	12.78	12.74
3	324	3190	20'5"	4'1"	16'7"	41'	5-5/16"	12.76	12.76	12.75
4	6903	2515	-2"[3]	14'7"	38'3"	56'6"	1-1/16"	12.77	12.77	12.74
5	6106	3200	2'5"	5'10"	36'5"	44'8"	1-7/8"	12.76	12.81	12.76
6	2796	2700	46'8"	4'8"	3/8"	51'5"	2-1/16"	12.75	12.77	12.81
7	6102	2700	36'9"	7'9"	1"	44'7"	15/16"	12.76	12.79	12.78

Notes:
1. To the nearest inch
2. Joint 2797 had two ruptures approximately 2" apart.
3. Joint 6903 had a short pup on the upstream end with a second girth near the end of the pup. The rupture crossed the girth weld into the pup for approximately 2". The upstream end of the rupture was 3'8" from the girth weld near the end of the pup.

Figure 1

Failure pressures and dimensions for the first seven burst tests.



			Dimensions[1]					O.D., in		
Test No.	Joint No.	Pressure, psi	1	2	3	4	5	1	2	3
15	3645	2650	29'0"	5'1"	24'5"	58'6"	3-3/4"	12.74	12.75	12.75
16	332	3250[2]	8'1"	10'9"	40'3"	58'3"	2-3/4"	12.77	12.91	12.77
17	6005	2900	50'8"	6'3"	6'0"	57'5"	1-1/2"	12.75	12.76	12.74
18	7634	3100	0"	2'9"	55'8"	58'5"	3-3/4"	12.72	12.77	12.75
19	2405	3050	46'10"	7'10"	4'6"	59'2"	1-1/4"	12.77	12.79	12.78
20	386	2770	29'11"	7'3"	21'4"	58'7"	2"	12.75	12.8	12.75
21	8769	2850[3]	13'	4'7"	40'8"	47'2"	2"	12.74	12.77	12.75

Notes: 1. To the nearest inch.
2. Due to pump malfunction, pressurized three times to 3000, 3250, and 2970 psi.
3. Due to pump malfunction, pressurized two times to 2550 and 2850 psi.

Figure 3

Failure pressures and dimensions for the third seven burst tests.

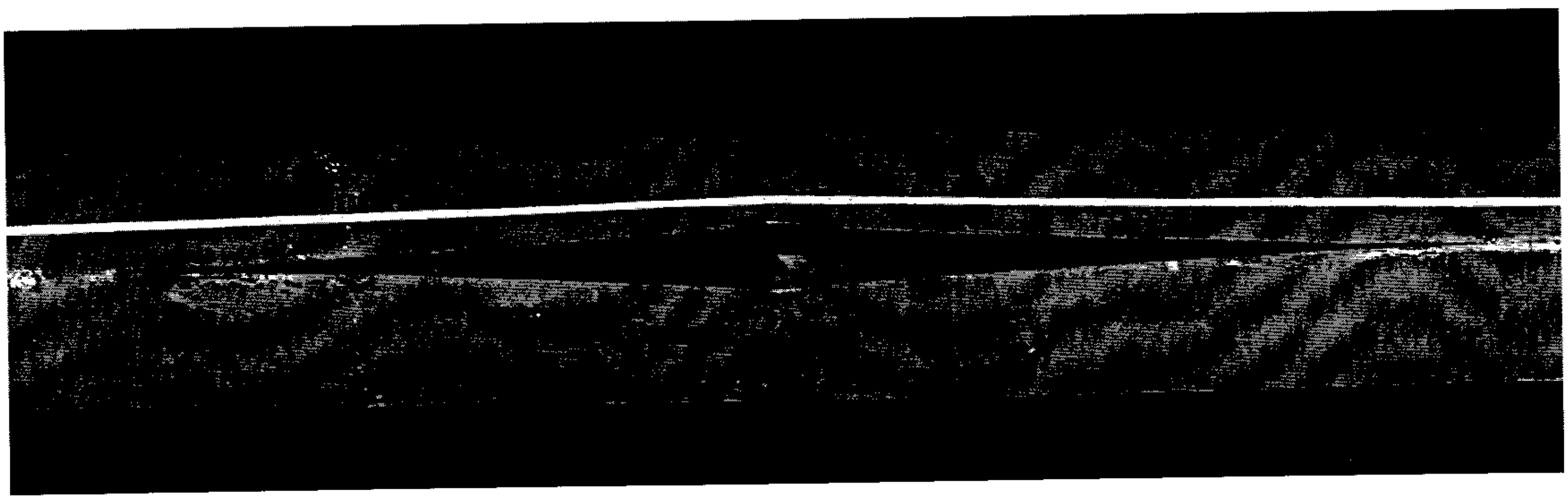


Figure 4

Photograph showing the rupture in Joint No. 6105.

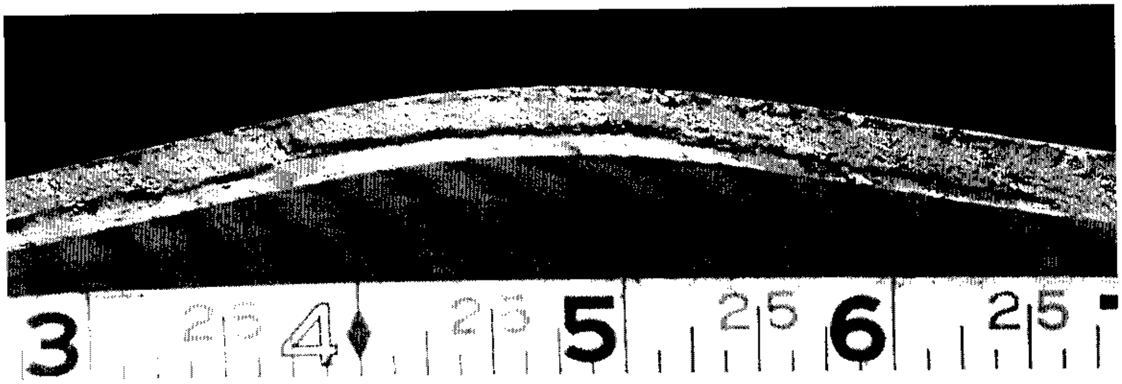


Figure 5 Joint No. 6105

Close-up view of the hook crack at the failure origin.

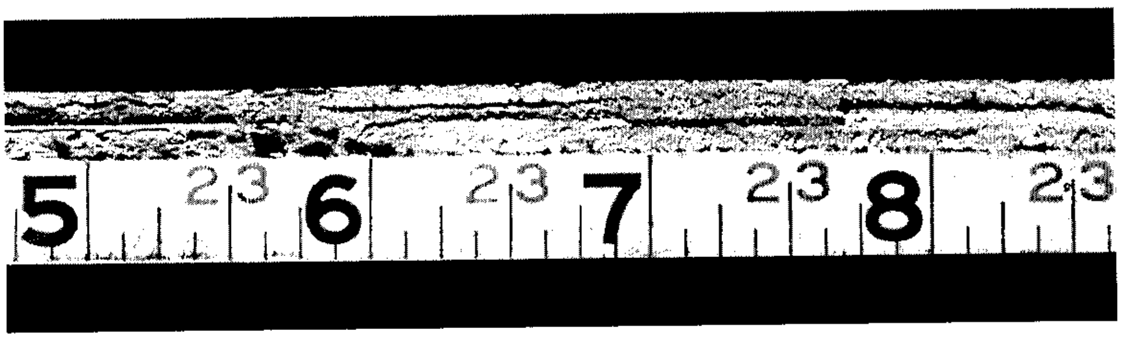


Figure 6 Joint No. 6105

Close-up view of the hook crack at the reported USCD indication.

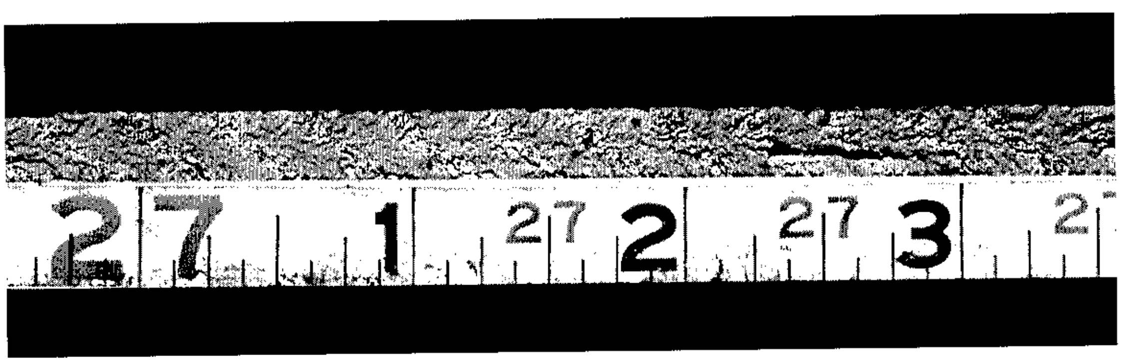
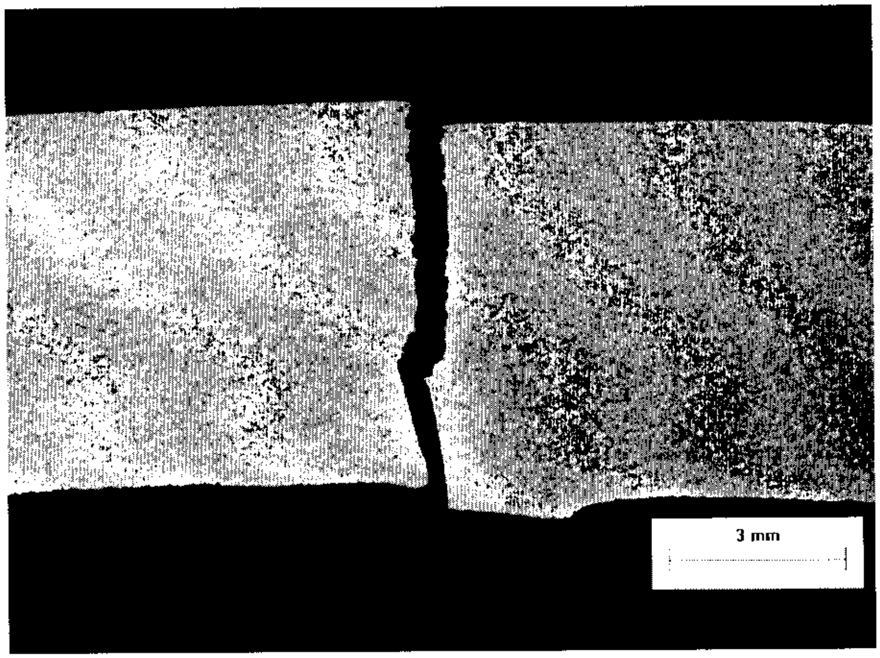


Figure 7 Joint No. 6105

Typical hook cracks upstream from the failure origin.

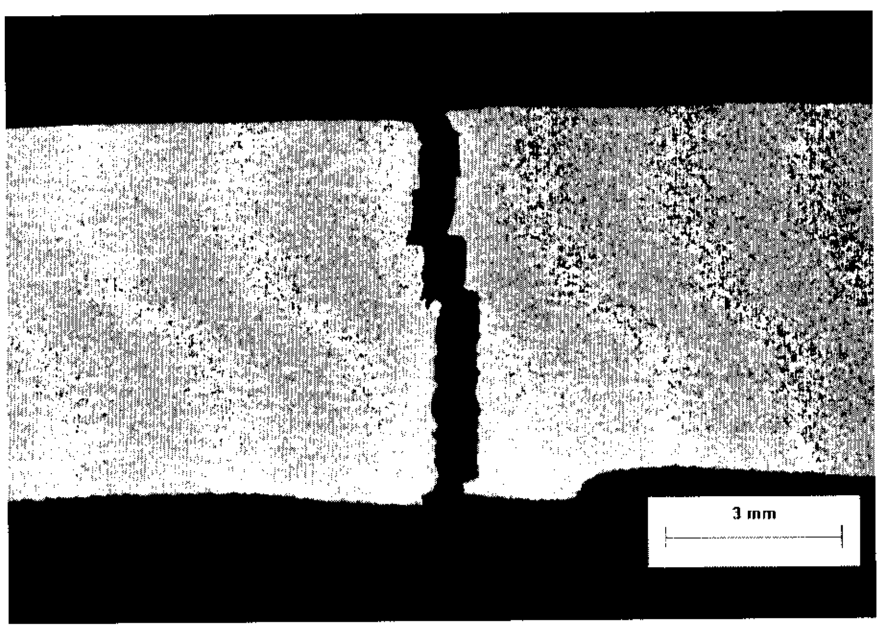


Joint No. 6105

Figure 8

8X
Nital Etch

Matching transverse sections from the hook crack shown in Figure 5.

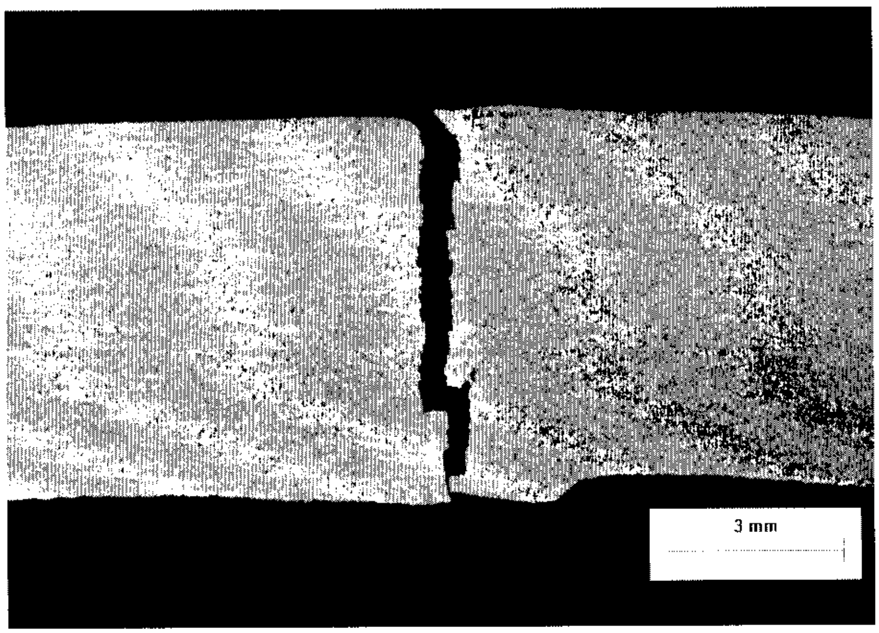


Joint No. 6105

Figure 9

8X
Nital Etch

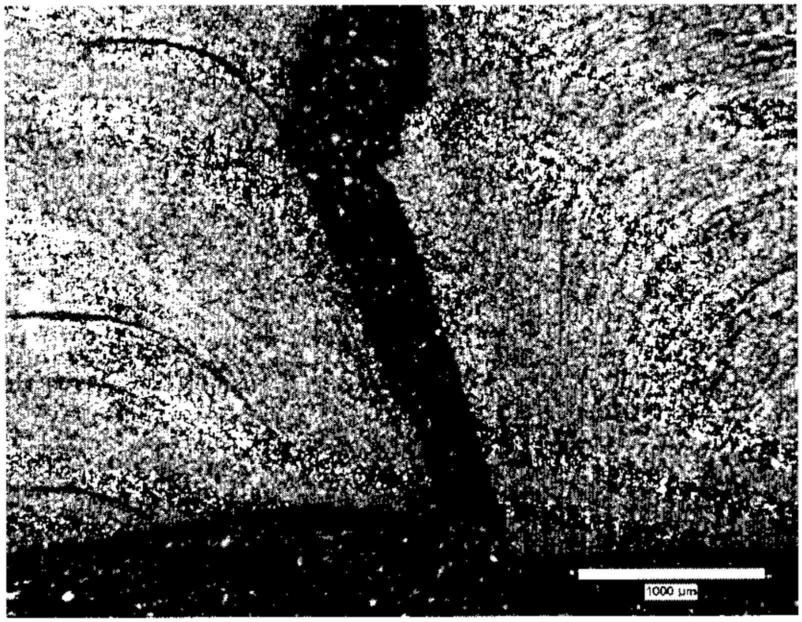
Matching transverse sections from the hook crack shown in Figure 6.



Joint No. 6105 8X

Figure 10 Nital Etch

Matching transverse sections from the hook crack shown in Figure 7.



Joint No. 6105 25X

Figure 11 Hot Picric Acid Etch

View at higher magnification at the inside surface of the section shown in Figure 8 after etching.

Joint No. 6105 25X

Figure 12 Hot Picric Acid Etch

View at higher magnification at the outside surface of the section shown in Figure 9 after etching.

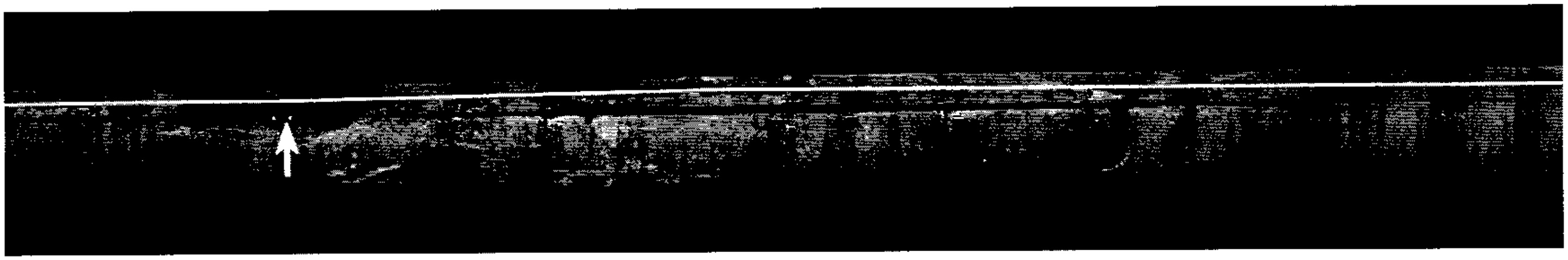


Figure 13 Joint No. 2797

Figure 14 Joint No. 2797

Figure 13 shows the two ruptures in Joint No. 2797, with an arrow indicating the intact area between them, shown in a closer view in Figure 14.

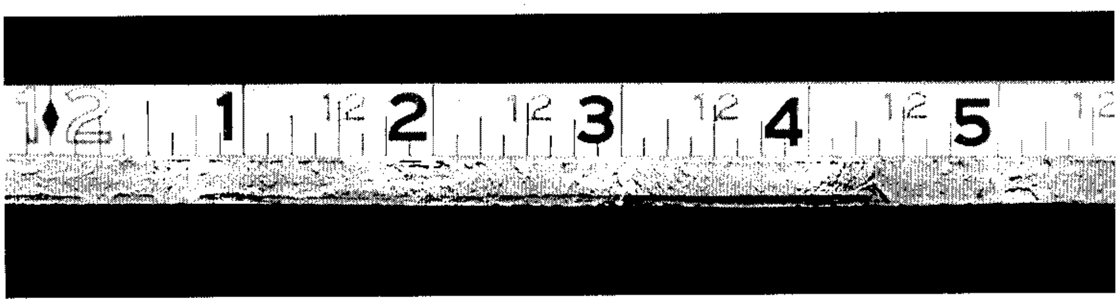


Figure 15 <u>Joint No. 2797</u>

Photograph showing a long hook crack on the outside surface (at bottom).

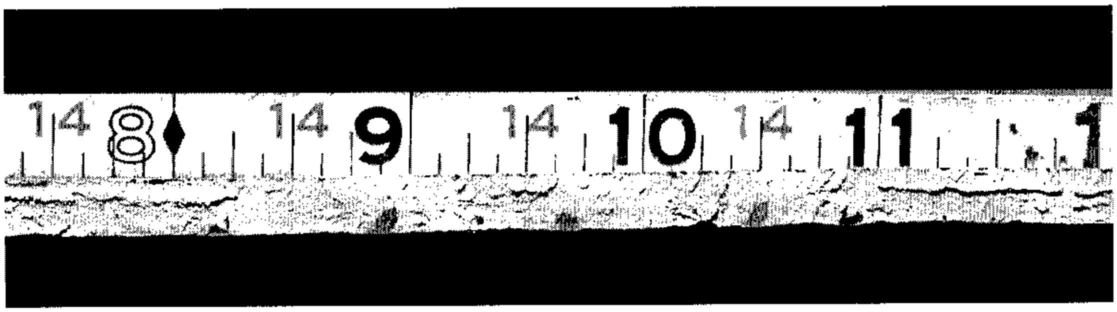


Figure 16 Joint No. 2797

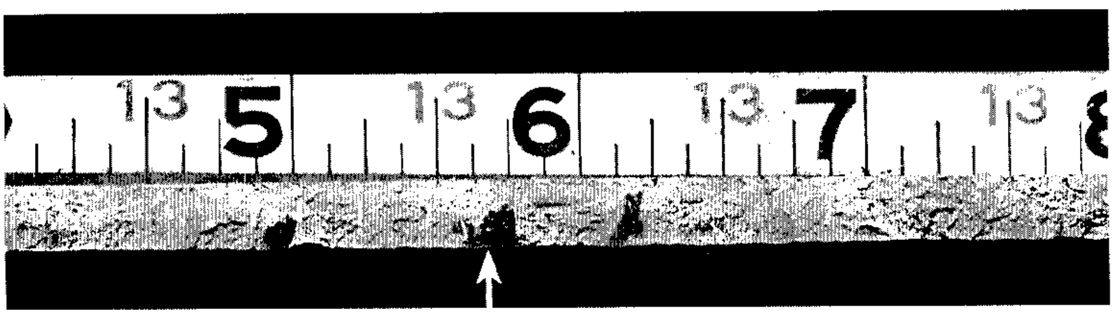
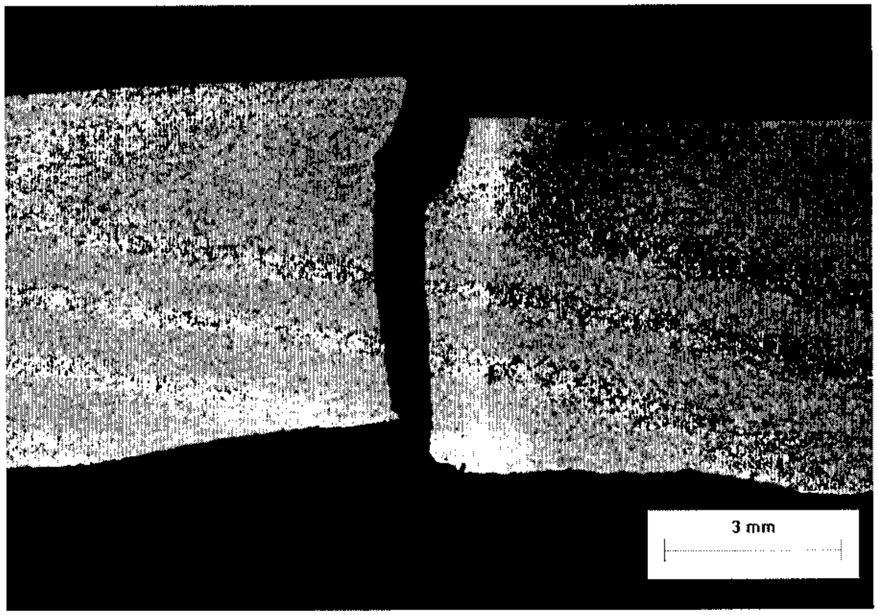


Figure 17 Joint No. 2797

Photographs showing typical black spots on the outside surface (at bottom). The arrow in Figure 17 indicates the deepest flaw.



Joint No. 2797 8X

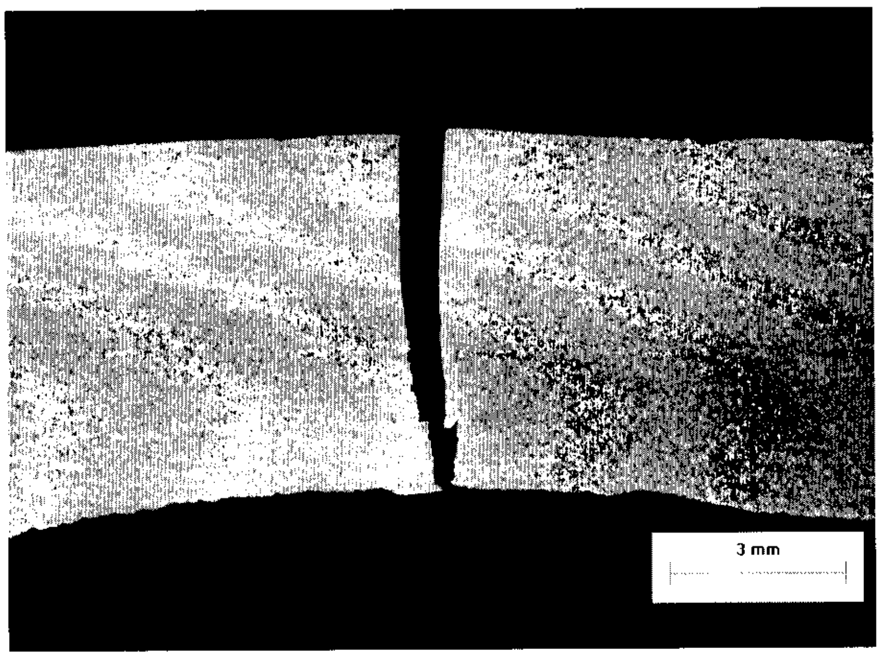
Figure 18 Nital Etch

Matching transverse sections from the hook crack shown in Figure 15.

Joint No. 2797 25X

Figure 19 Hot Picric Acid Etch

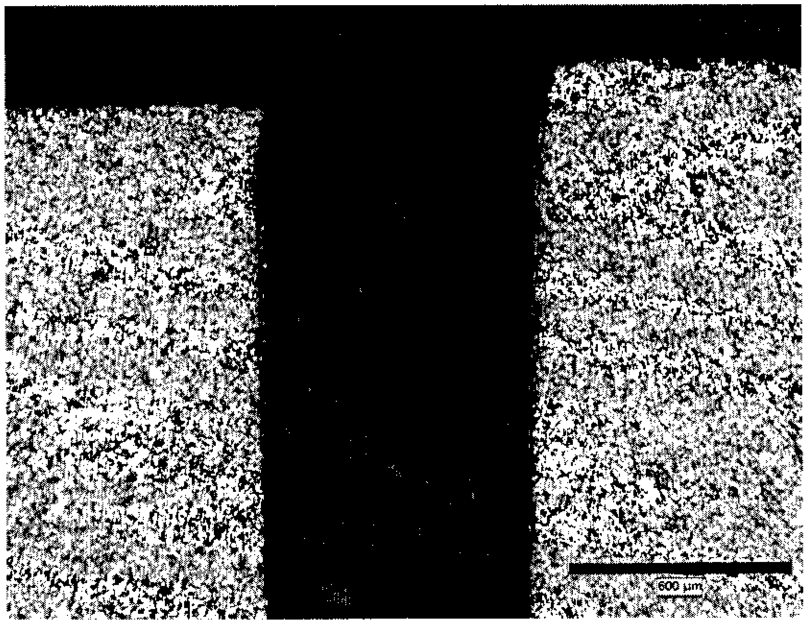
Outside surface of the hook crack after etching. The arrow indicates the weld line.



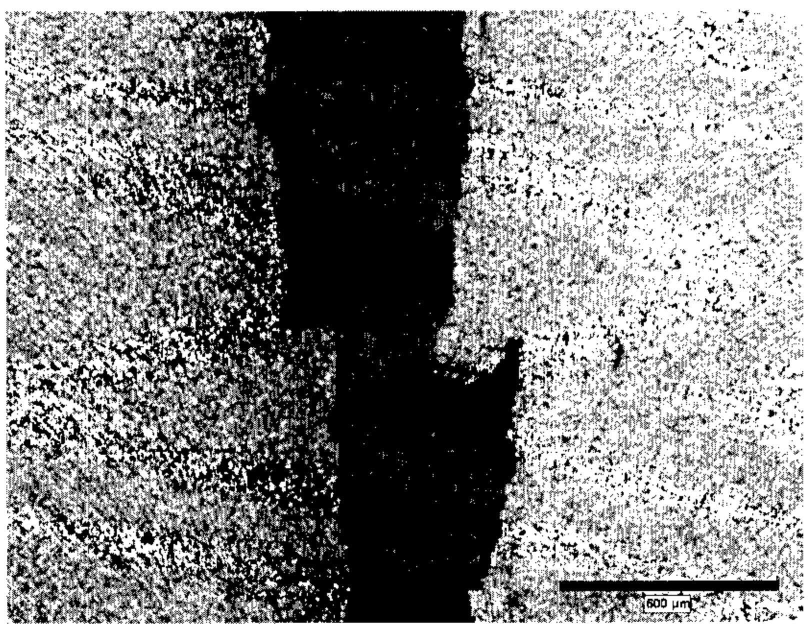
Joint No. 2797 8X

Figure 20 Nital Etch

Matching transverse sections from the black spot shown in Figure 17.



Joint No. 2797 50X
Figure 21 Nital Etch



Joint No. 2797 50X
Figure 22 Nital Etch

Photomicrographs showing the black spot at the outside surface, Figure 21, and near the inside surface, Figure 22.

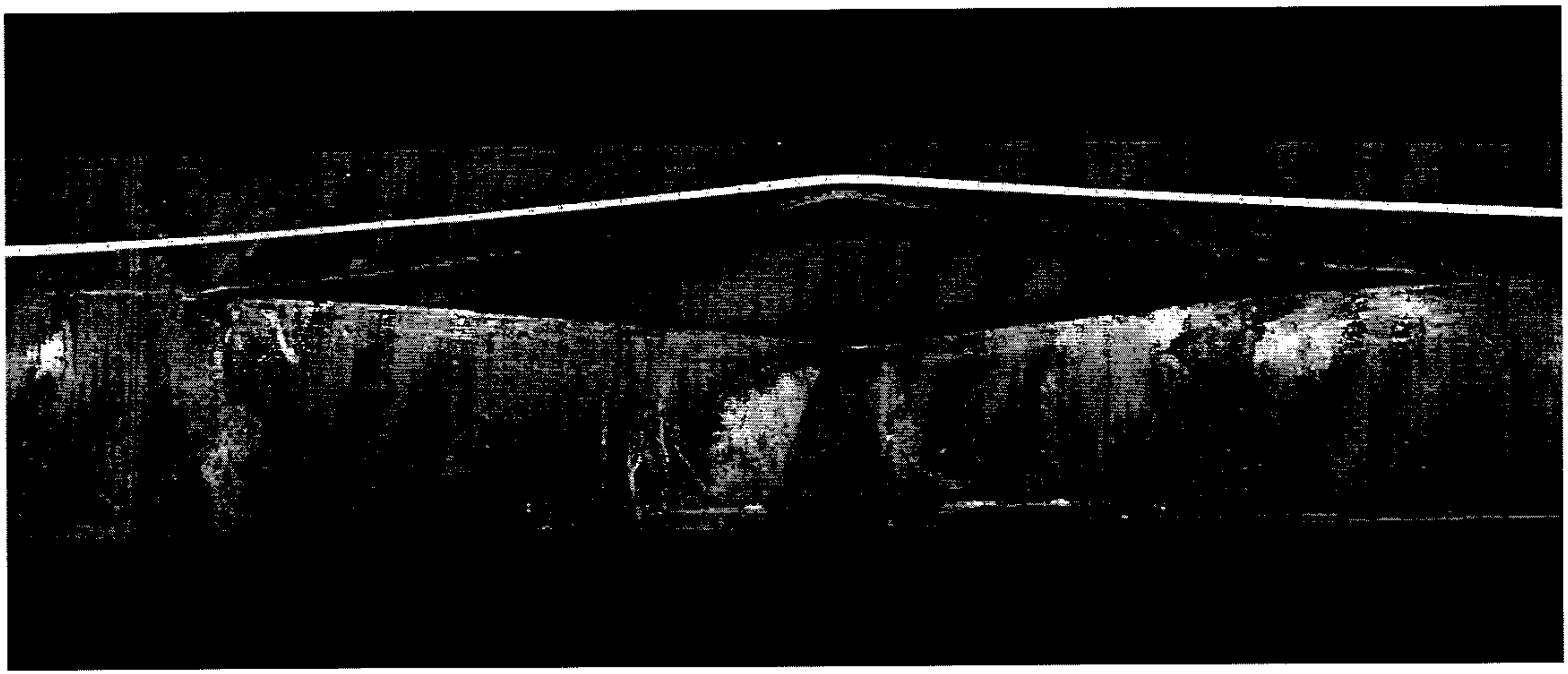


Figure 23 Joint No. 324

Photograph showing the rupture in Joint No. 324.

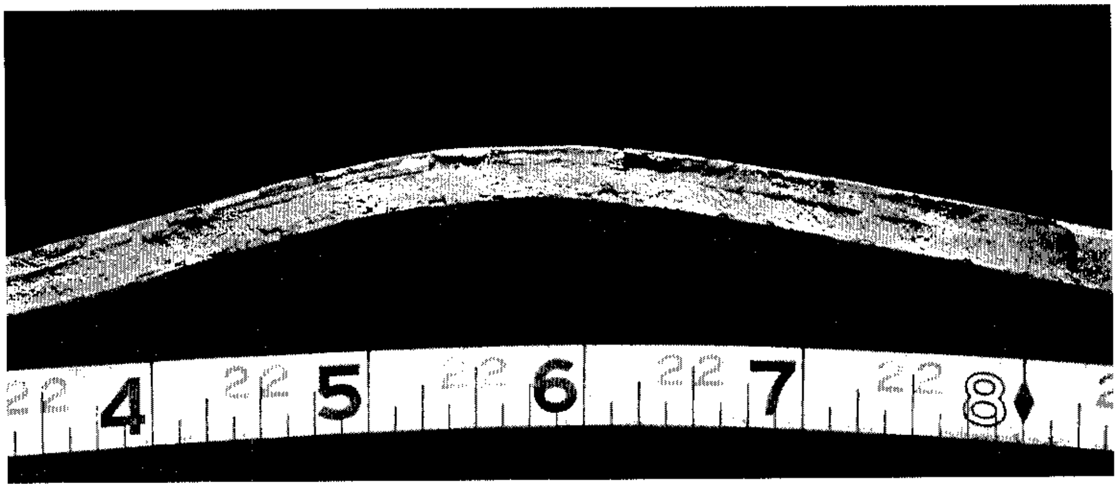


Figure 24 Joint No. 324

Photograph showing a hook crack at the outside surface at the apparent origin.

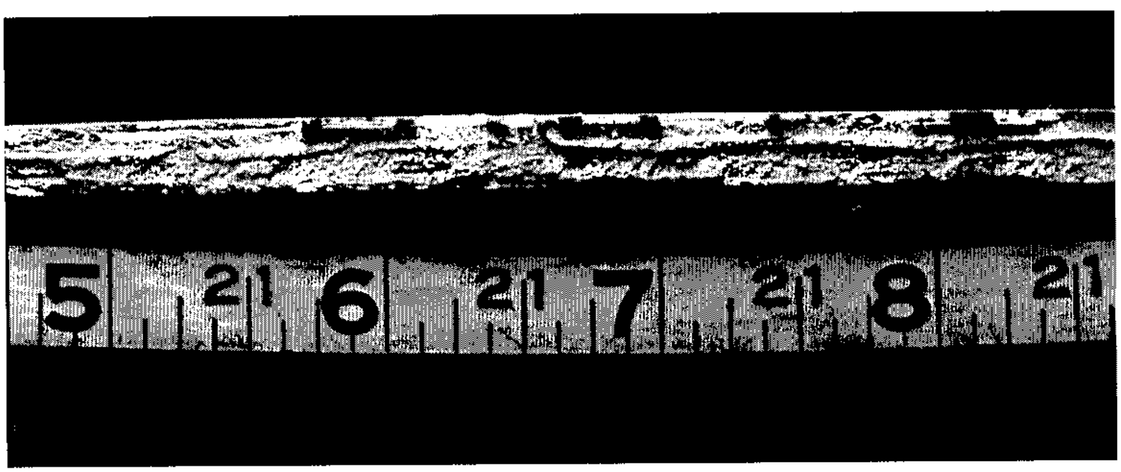
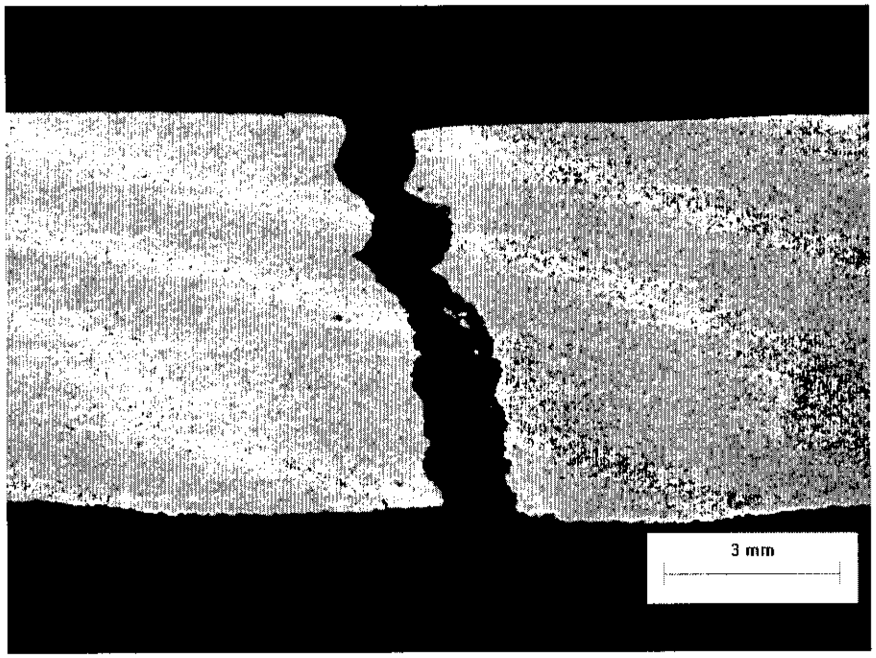


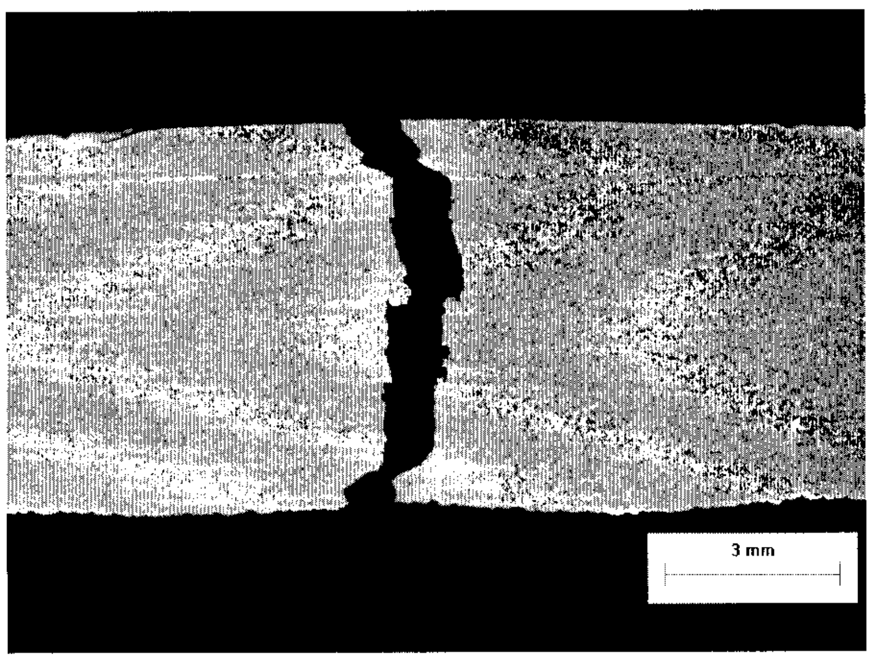
Figure 25 Joint No. 324

Photograph of a typical hook crack found along the rupture.



Joint No. 324 8X

Figure 26 Nital Etch



Joint No. 324 8X

Figure 27 Nital Etch

Figure 26 shows the sections from the hook crack at the apparent failure origin, and Figure 27 shows the sections from the hook crack shown in Figure 25.

Joint No. 324 25X

Figure 28 Hot Picric Acid Etch

Photomicrograph showing the hook crack at the fracture origin after etching.

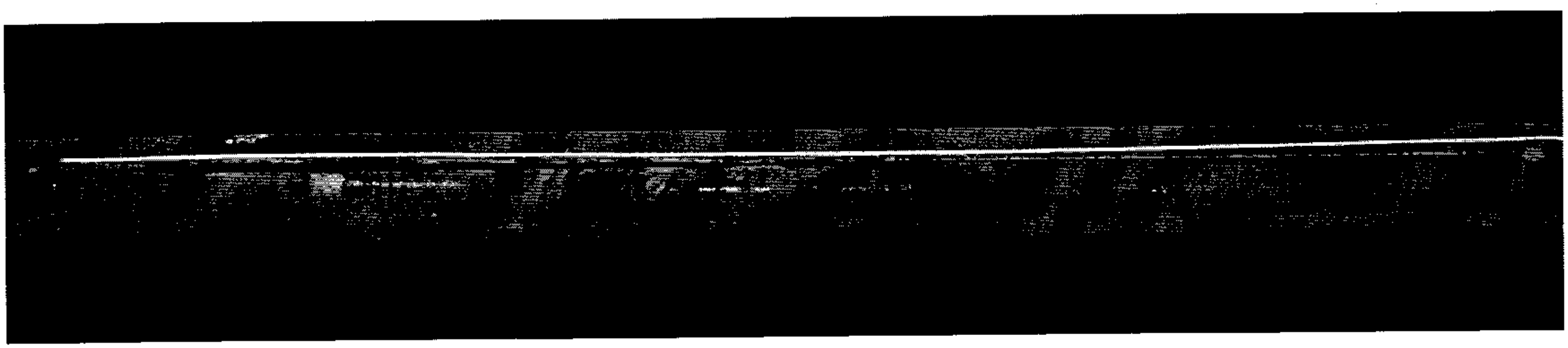


Figure 29 Joint No. 6930

Photograph showing the rupture in Joint No. 6903.

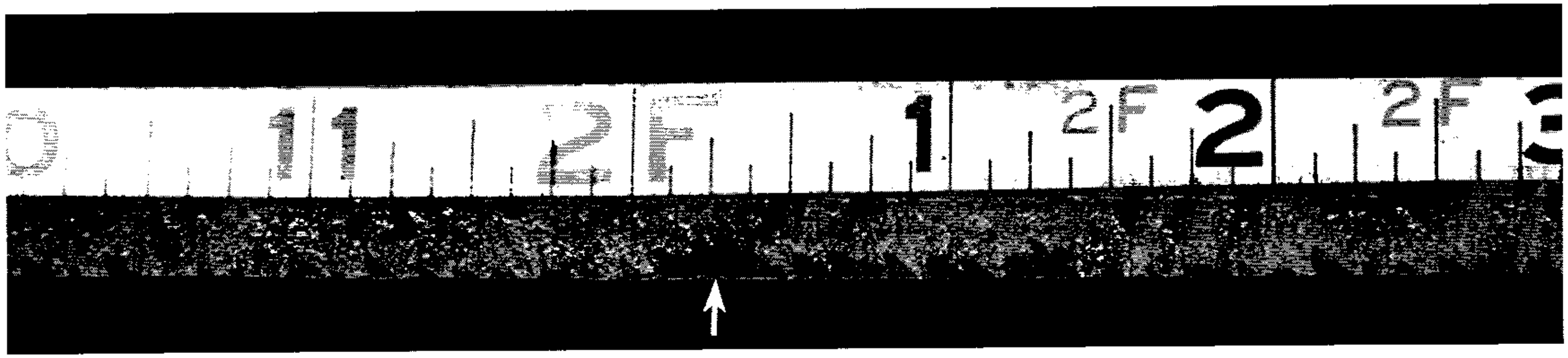


Figure 30 Joint No. 6930

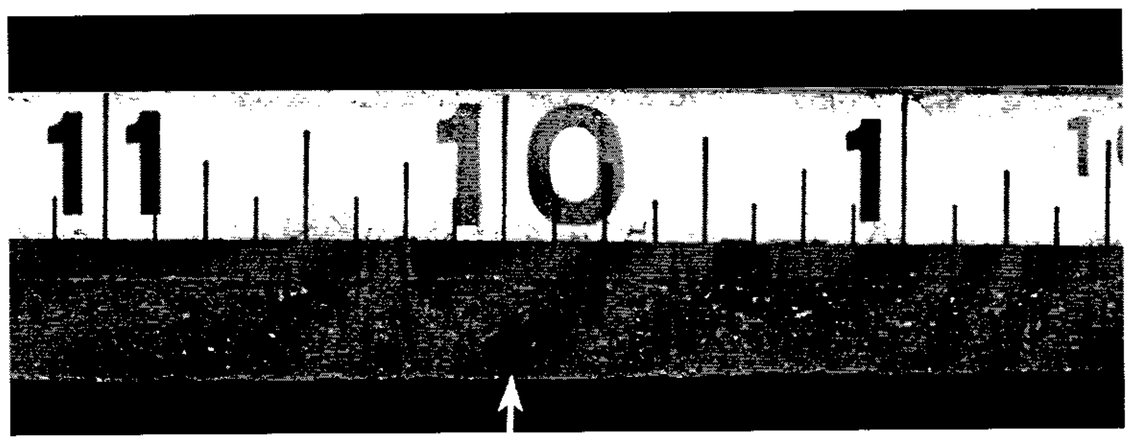
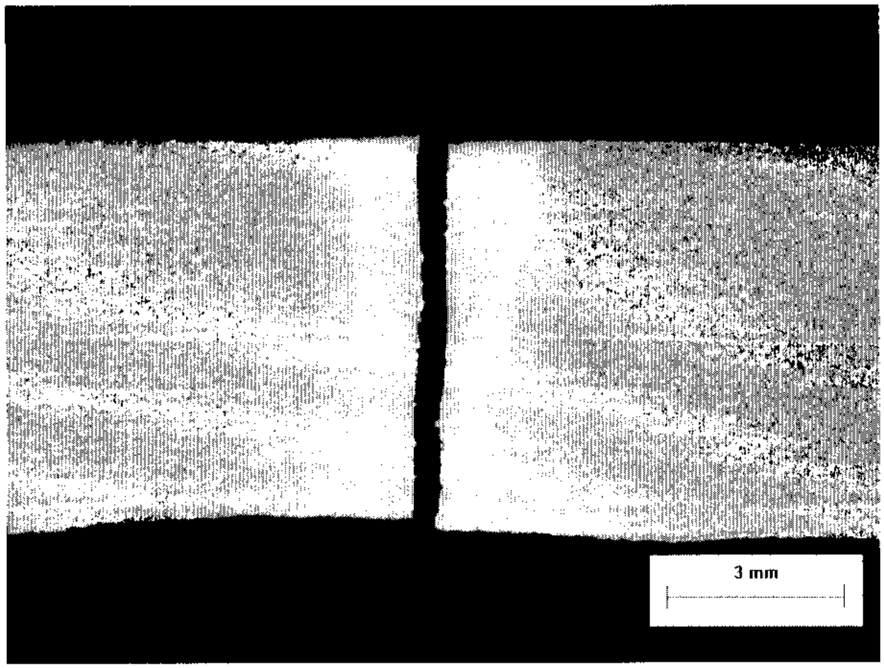


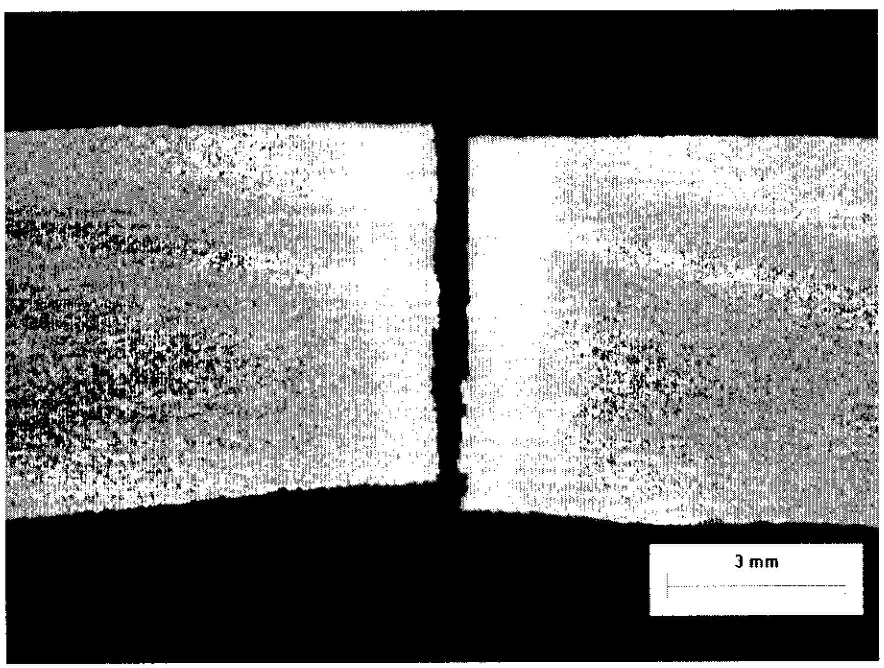
Figure 31 Joint No. 6930

Photographs of a concentration of black spots on the outside surface, Figure 30, and of three black spots at a PAUT indication, Figure 31. The arrows indicate locations from which metallographic sections were taken.



Joint No. 6930 8X

Figure 32 Nital Etch



Joint No. 6930 8X

Figure 33 Nital Etch

Photomacrographs showing the sections from the black spots shown in Figures 30 and 31, respectively.

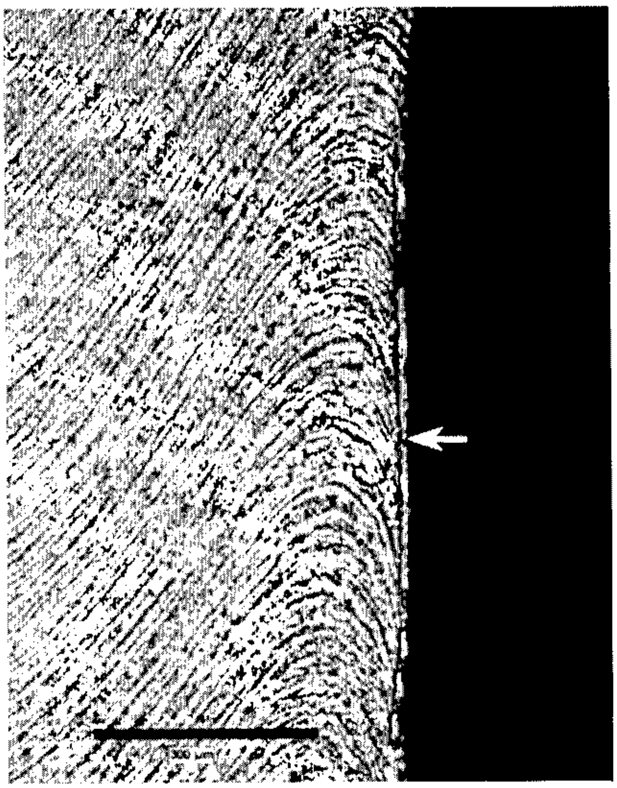


Figure 34 Joint No. 6930 50X Nital Etch

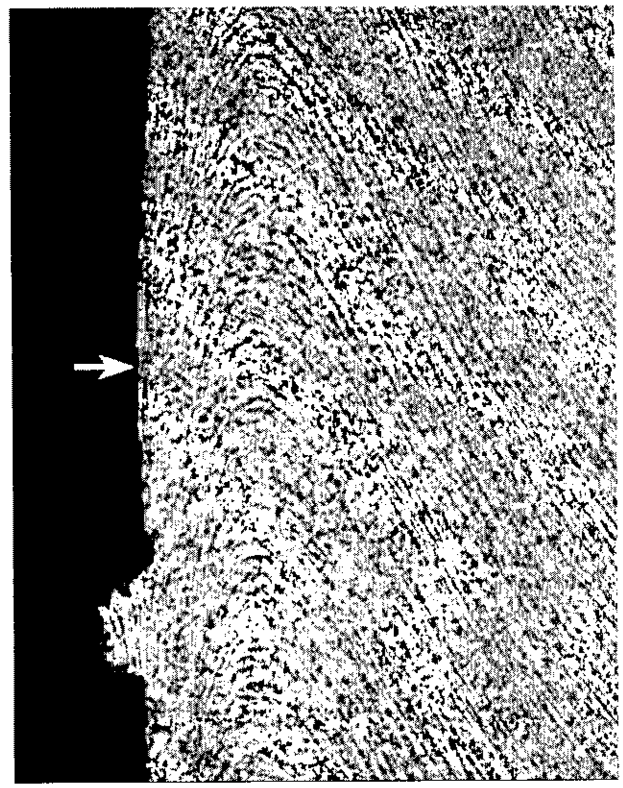


Figure 35 Joint No. 6930 50X Nital Etch

Photomicrographs showing a thin layer, arrows, along the surfaces of the black spot shown in Figure 30.

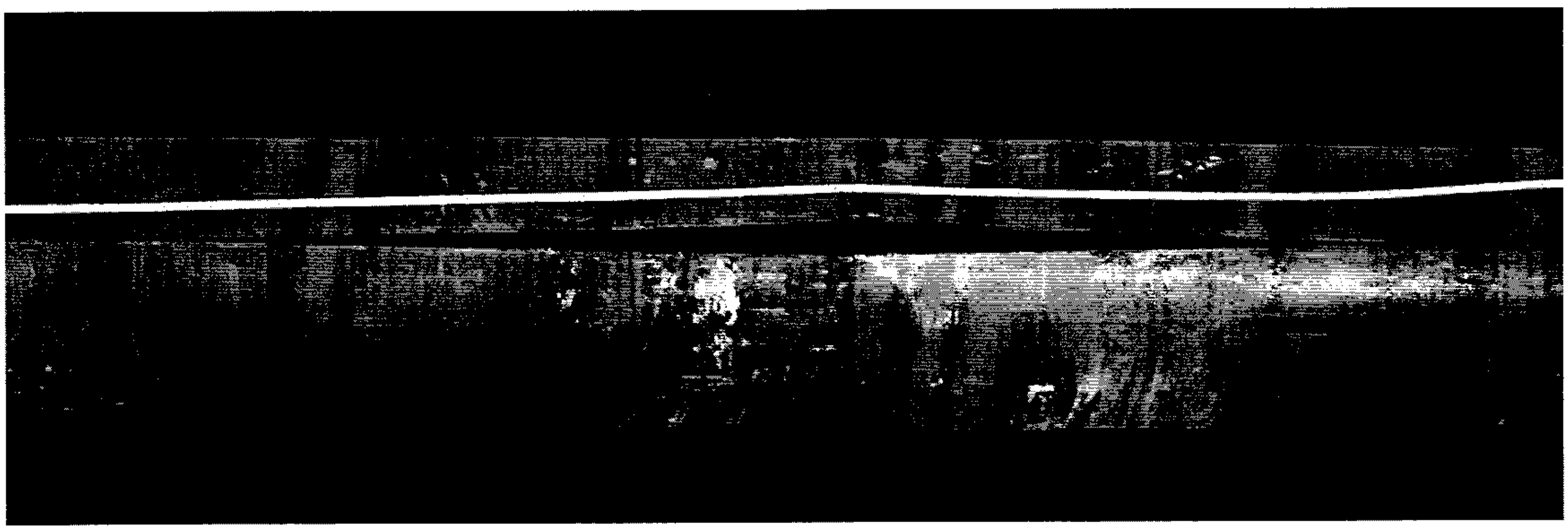


Figure 36 Joint No. 6106

Photograph showing the rupture in Joint No. 6106.

Figure 37 Joint No. 6106

Photograph showing the fracture surface at the bulge near the middle of the rupture. The arrow indicates a location from which a metallographic section was taken.

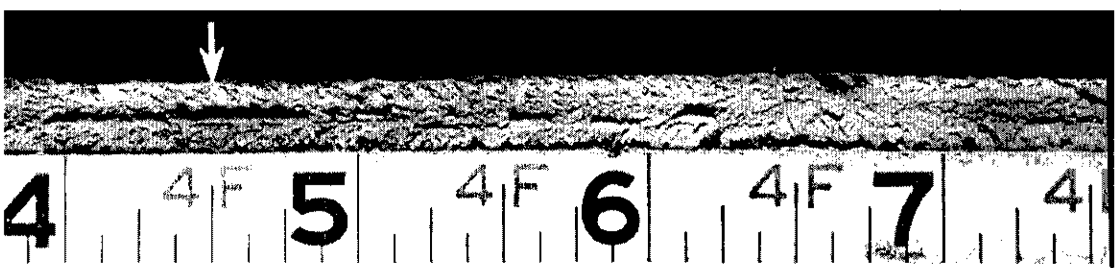
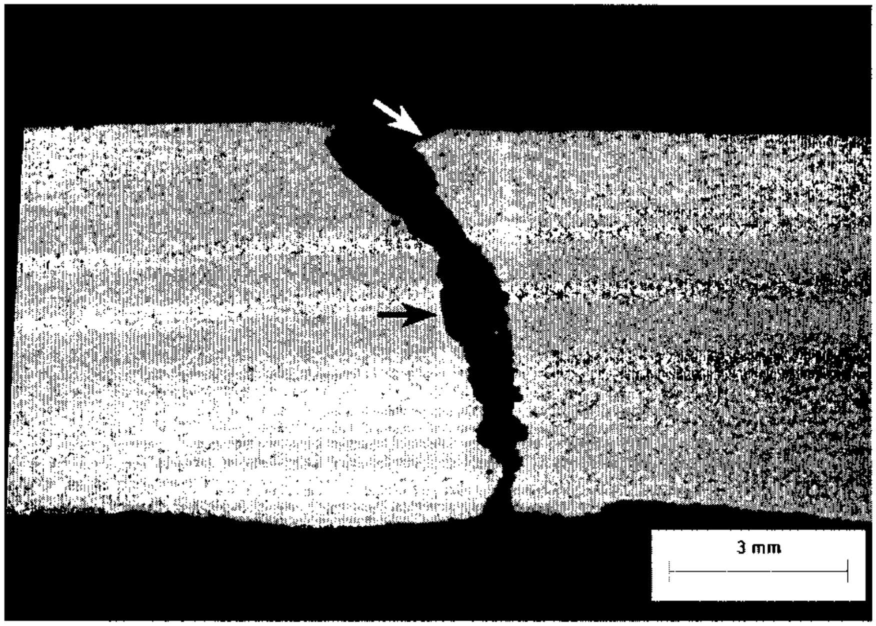


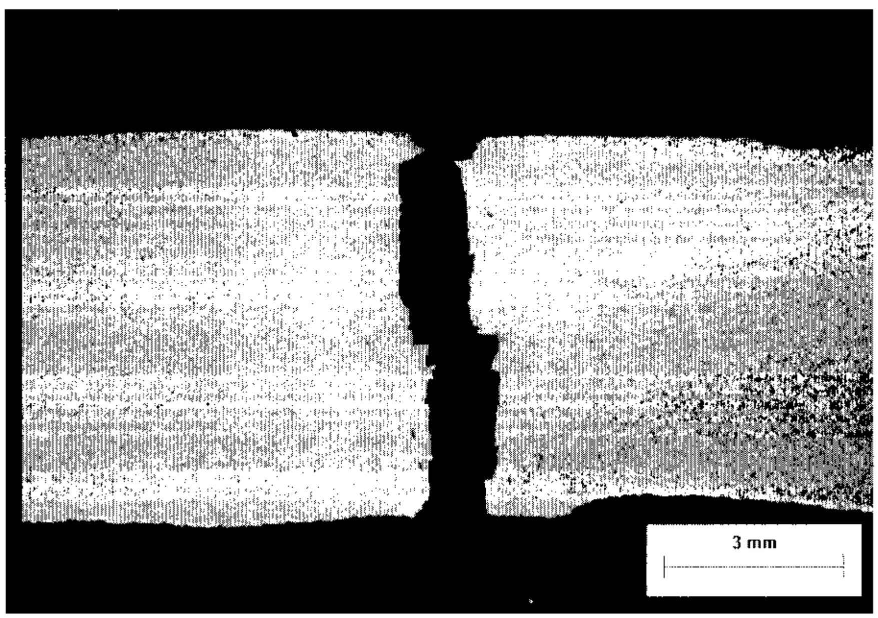
Figure 38 Joint No. 6106

Photograph showing the fracture surface at a reported PAUT indication. The arrow indicates a location from which a metallographic section was taken.



Joint No. 6106 8X

Figure 39 Nital Etch



Joint No. 6106 8X

Figure 40 Nital Etch

Matching transverse sections from the locations indicated by arrows in Figures 37 and 38, respectively. The white arrow in Figure 39 indicates mechanical damage, and the black arrow indicates the weld line.

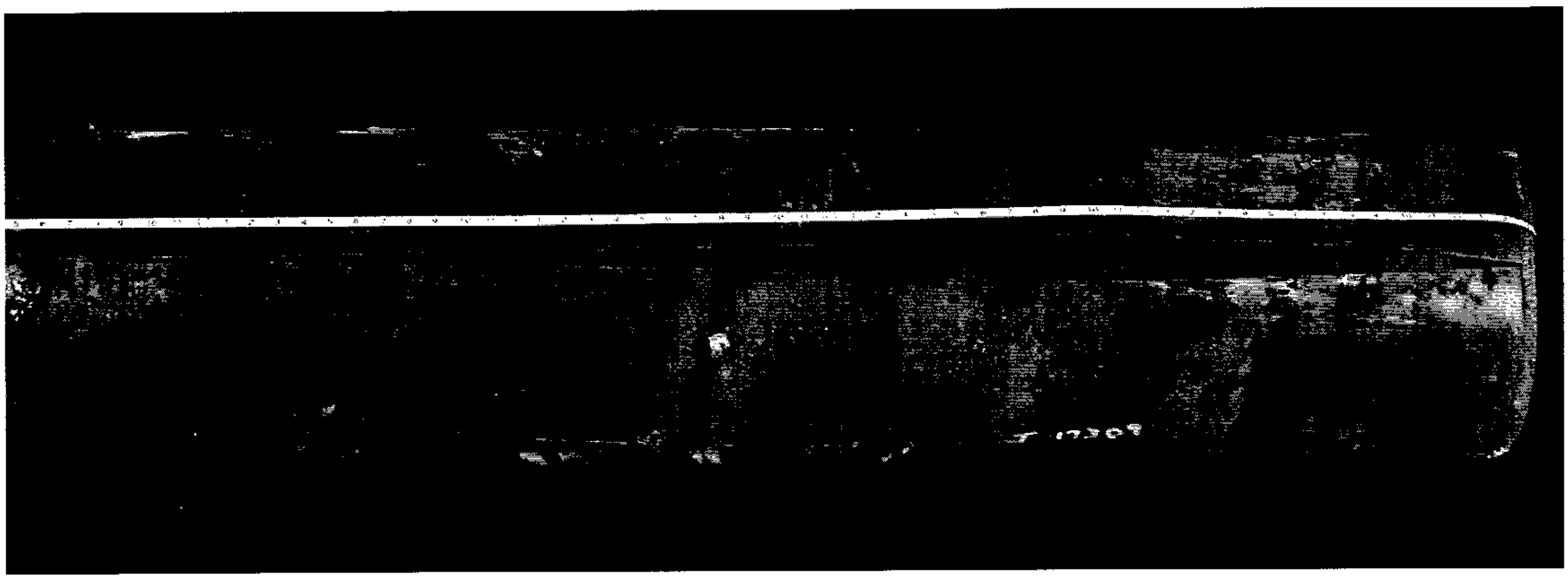


Figure 41 Joint No. 2796

Photograph showing the rupture in Joint No. 2796.

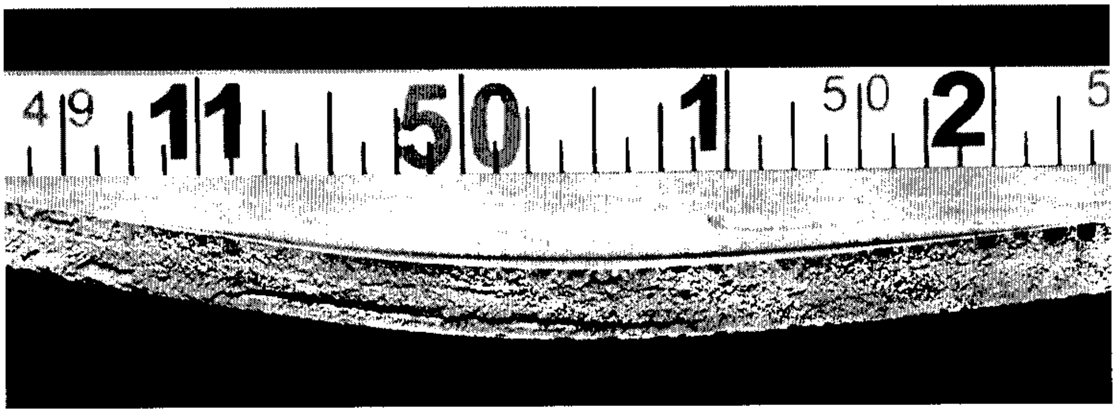


Figure 42 Joint No. 2796

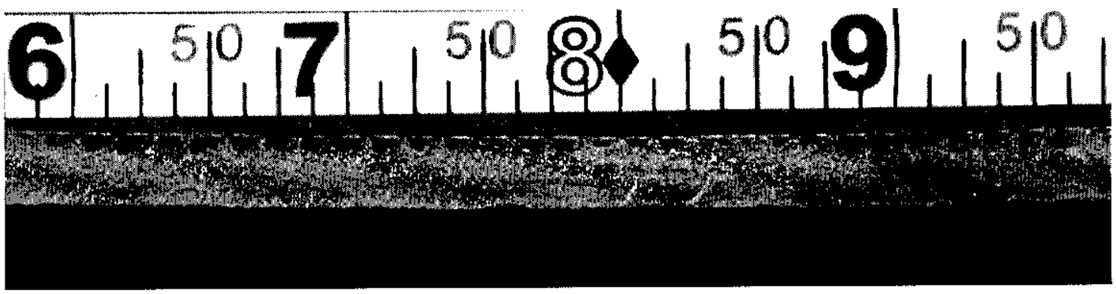
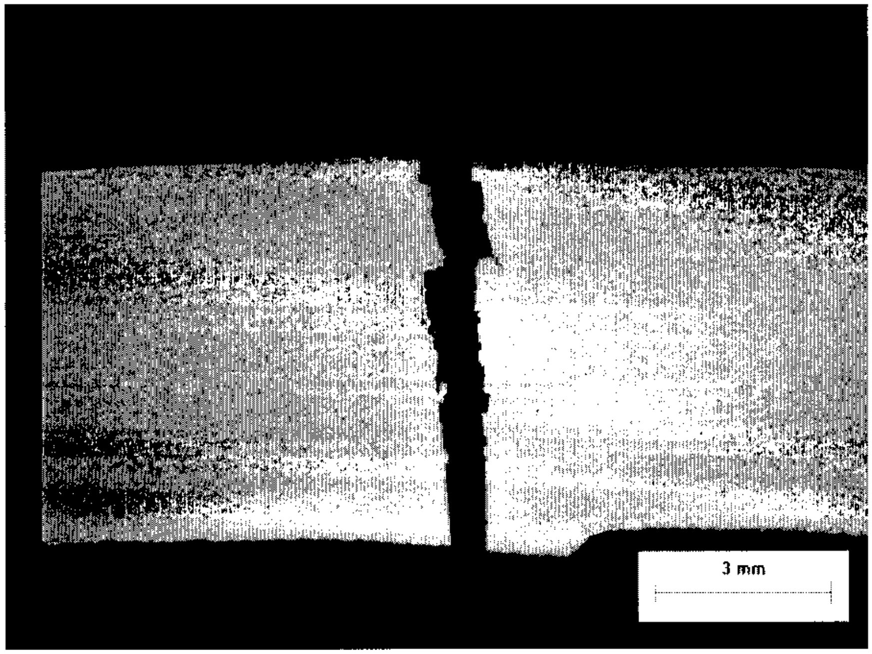


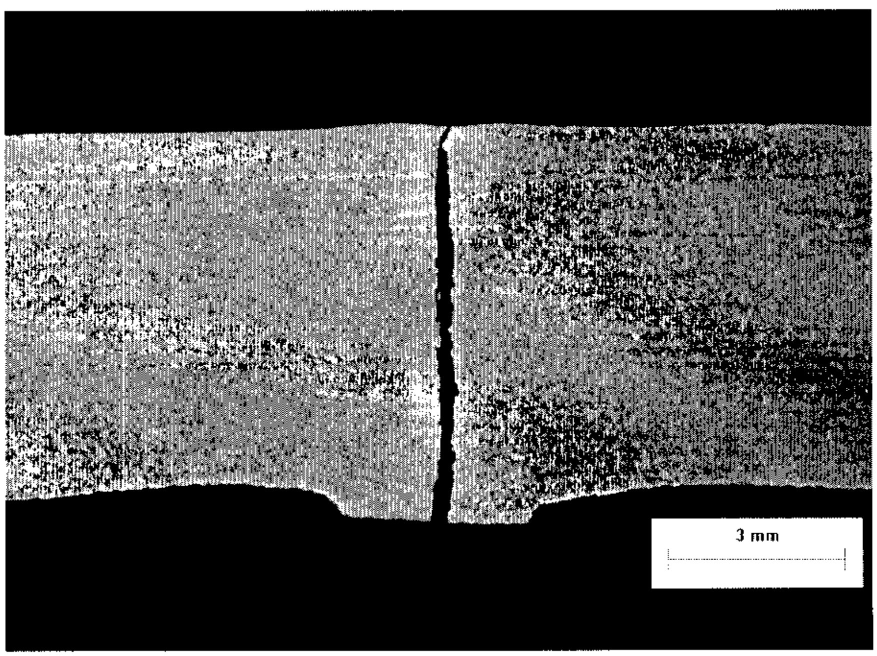
Figure 43 Joint No. 2796

Figure 42 shows the hook crack at the outside surface at the failure origin, and Figure 43 shows typical black spots at the inside surface.



Joint No. 2796 8X

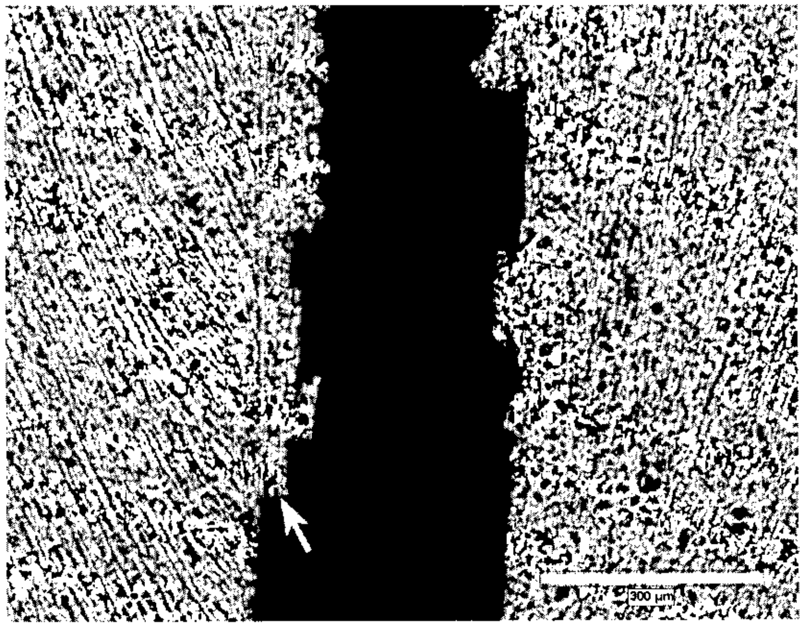
Figure 44 Nital Etch



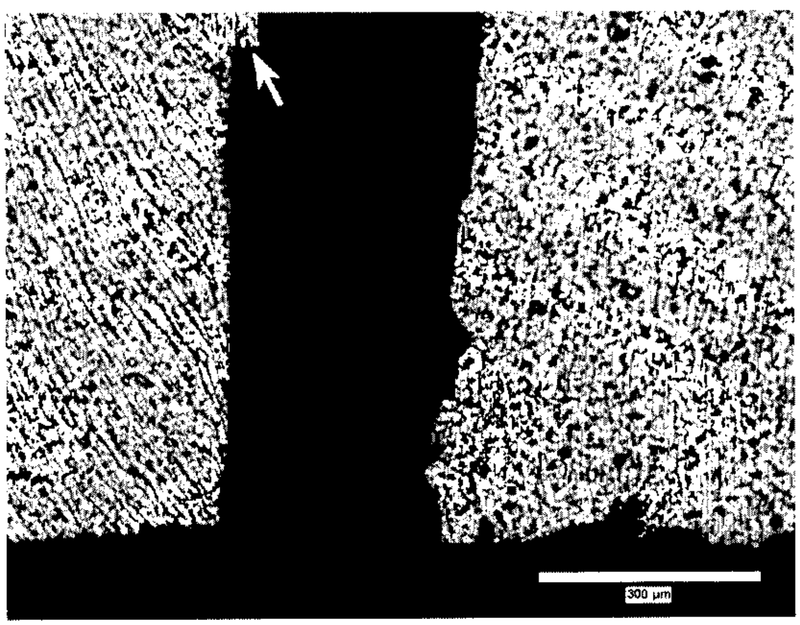
Joint No. 2796 8X

Figure 45 Nital Etch

Matching transverse sections from the hook crack and one of the black spots shown in Figures 42 and 43, respectively.



Joint No. 2796 100X
Figure 46 Nital Etch



Joint No. 2796 100X
Figure 47 Nital Etch

Figure 46 shows the jagged fracture just above the black spot, and Figure 47 shows the smooth fracture along the black spot, which was never fused. The arrows indicate the top of the black spot.

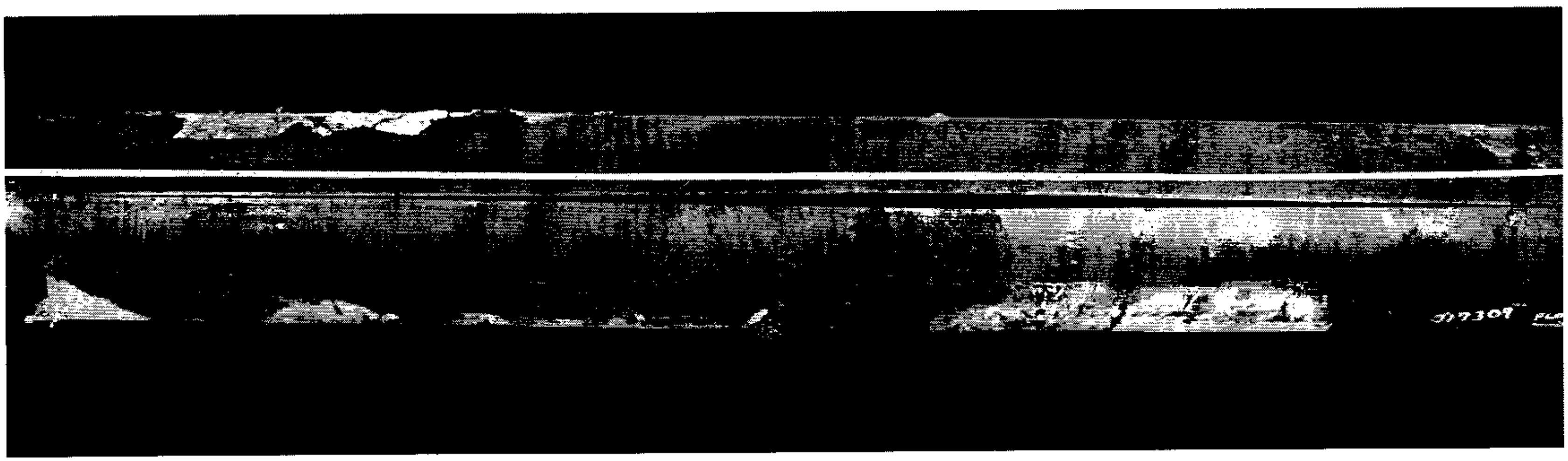


Figure 48 Joint No. 6102

Photograph showing the rupture in Joint No. 6102.

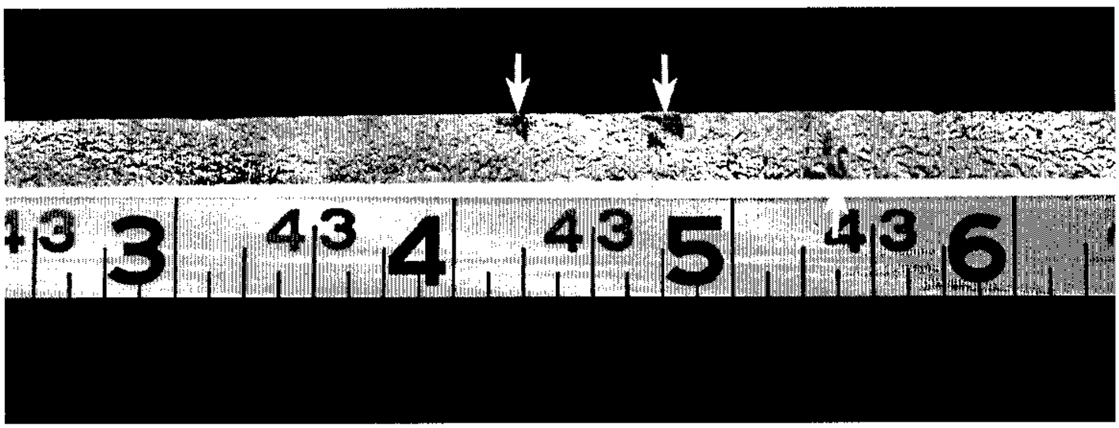


Figure 49 <u>Joint No. 6102</u>

Photograph showing black spots, arrows at the inside and outside surfaces. The deepest flaw was at the arrow near 43 feet, 5 inches.

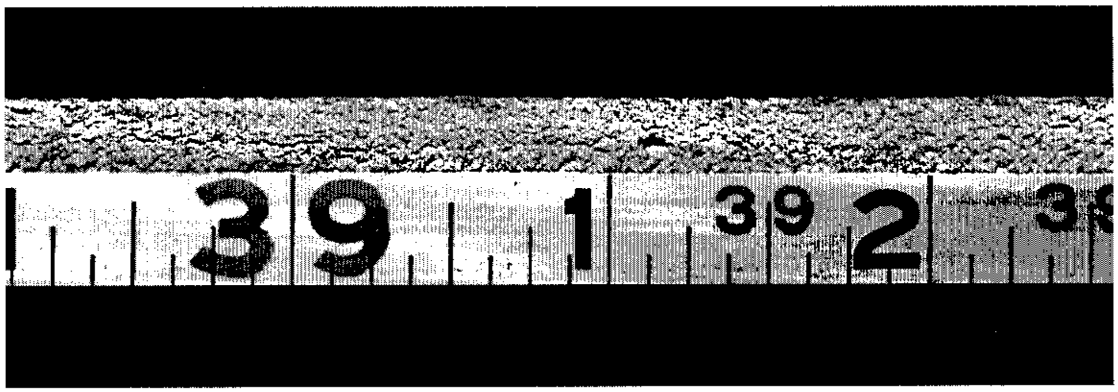


Figure 50 <u>Joint No. 6102</u>

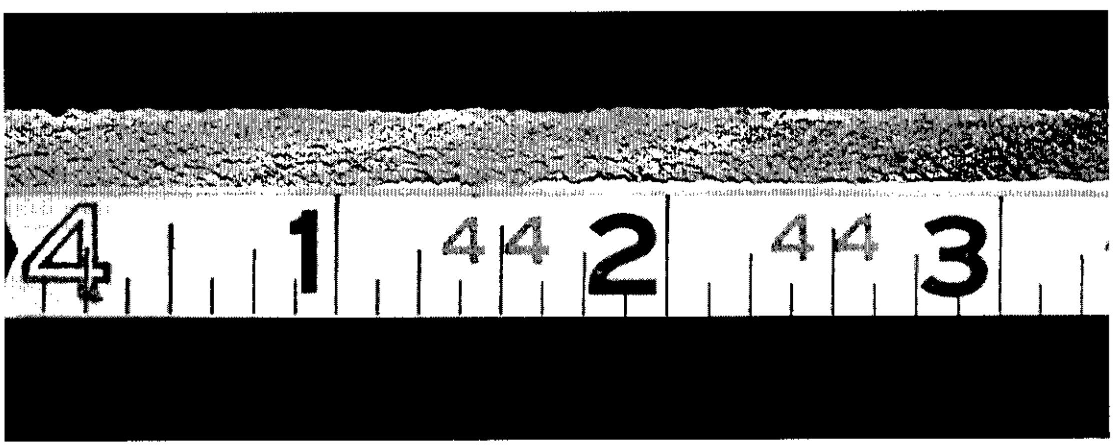
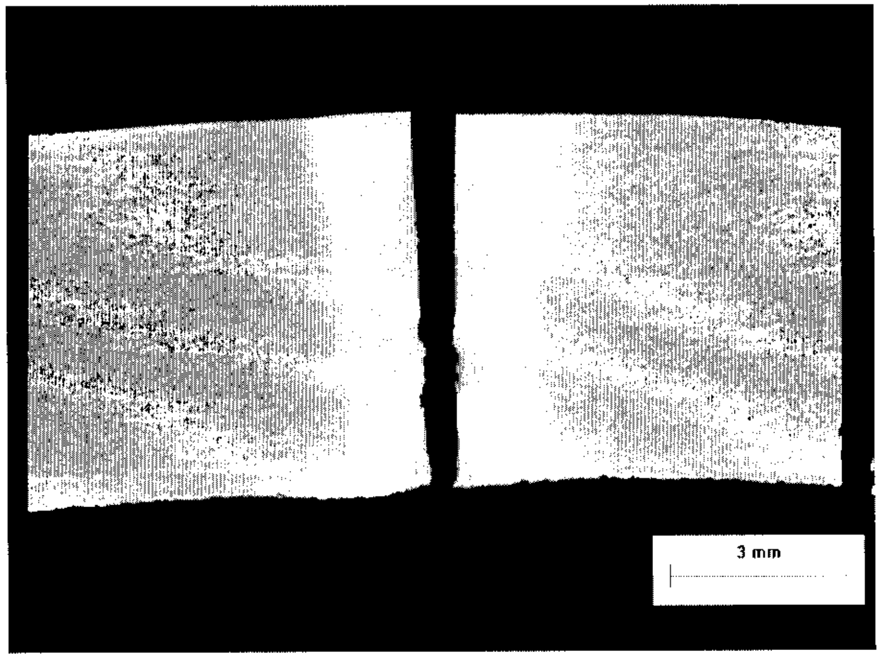


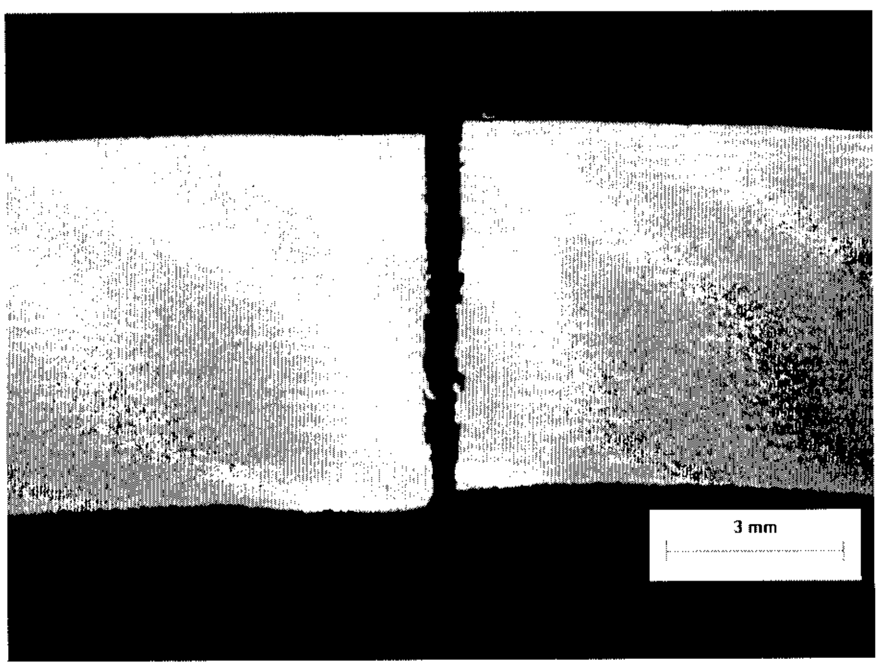
Figure 51 <u>Joint No. 6102</u>

Photographs showing the fracture surface at the two reported USCD indications.



Joint No. 6102 8X

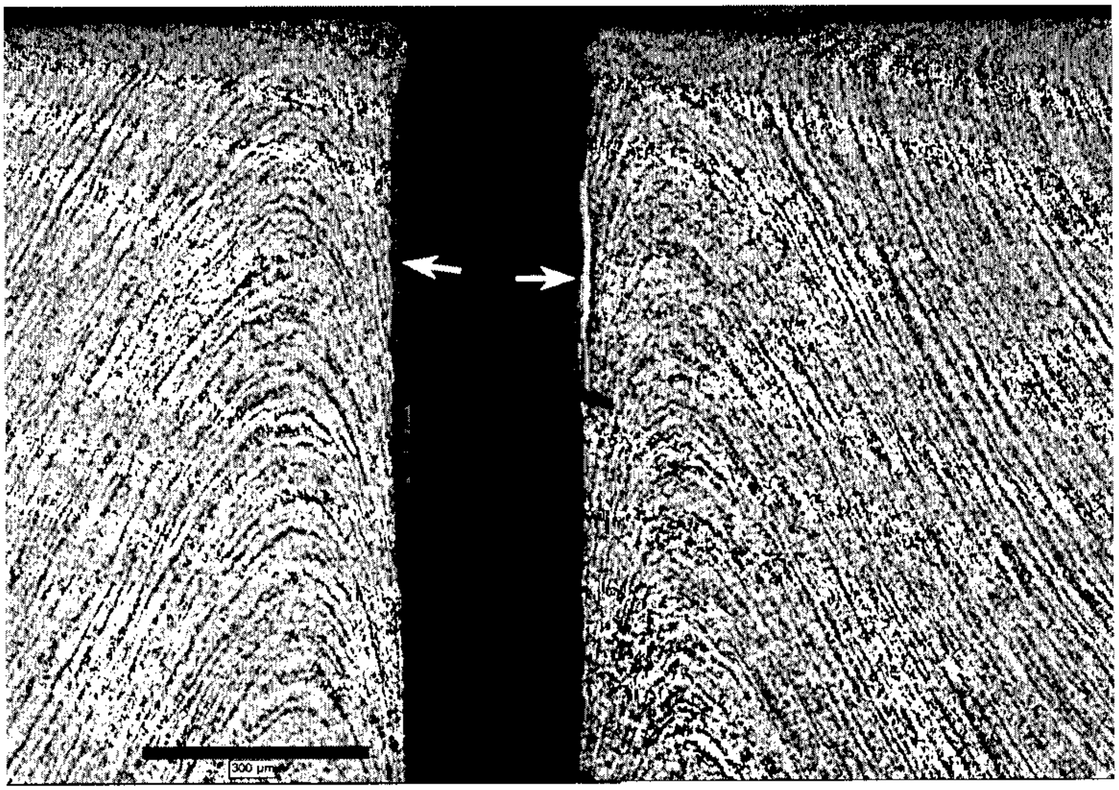
Figure 52 Nital Etch



Joint No. 6102 8X

Figure 53 Nital Etch

Matching transverse sections from the large black spot shown in Figure 49 and the hook crack shown in Figure 51, respectively.



Joint No. 6102

100X

Figure 54

Nital Etch

Composite photomicrograph showing the fracture at the outside surface of the sections shown in Figure 52. The arrows indicate a thin layer of scale at left, and of decarburized metal at right.

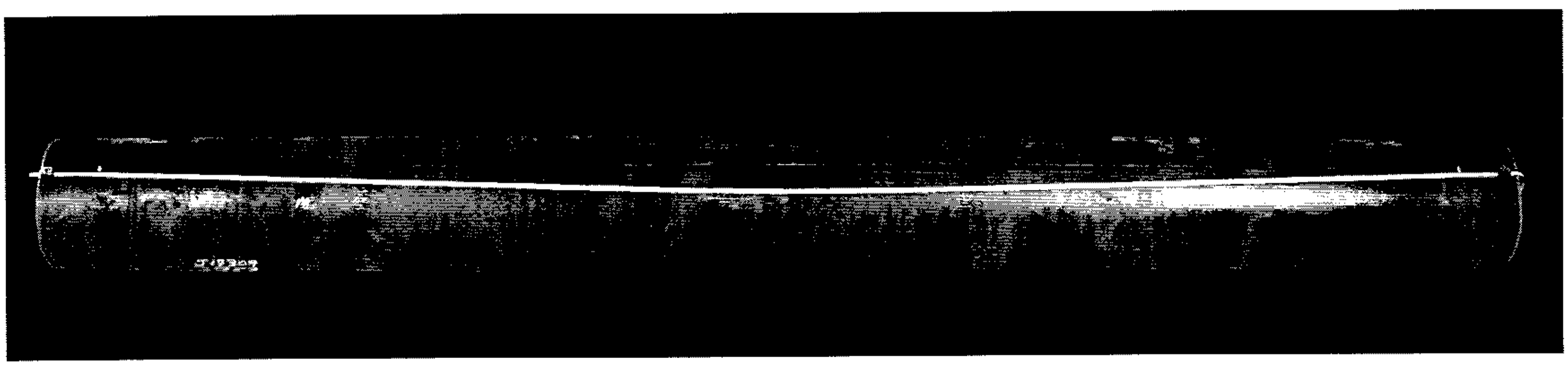


Figure 55 <u>Joint No. 2753</u>

Photograph showing the rupture in Joint No. 2753.

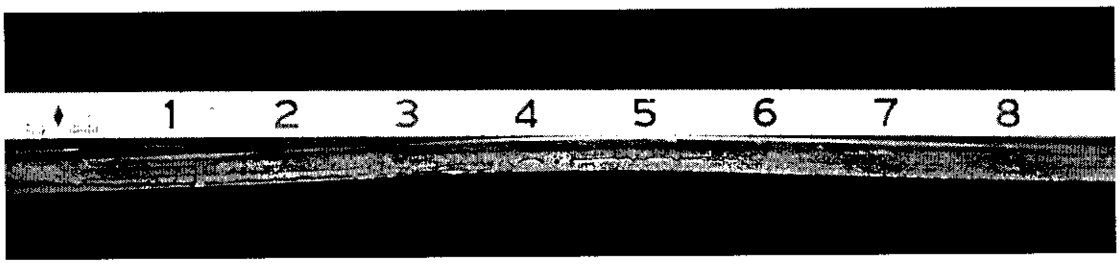


Figure 56 <u>Joint No. 2753</u>

Photograph showing a long hook crack at the outside surface at the failure origin. A USCD indication was reported at 32 feet, 4 inches.

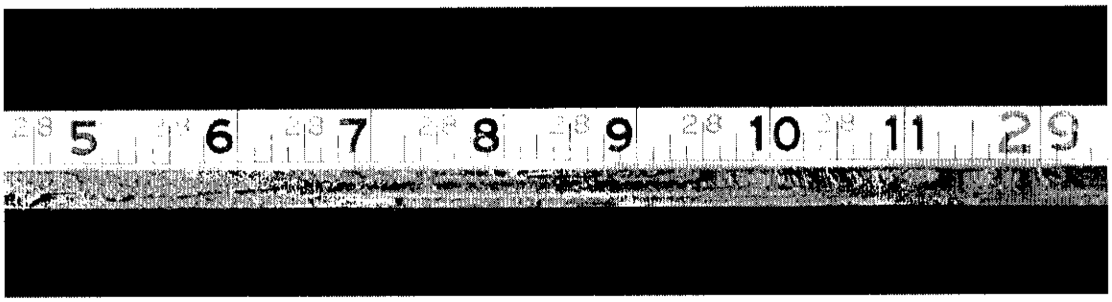


Figure 57 Joint No. 2753

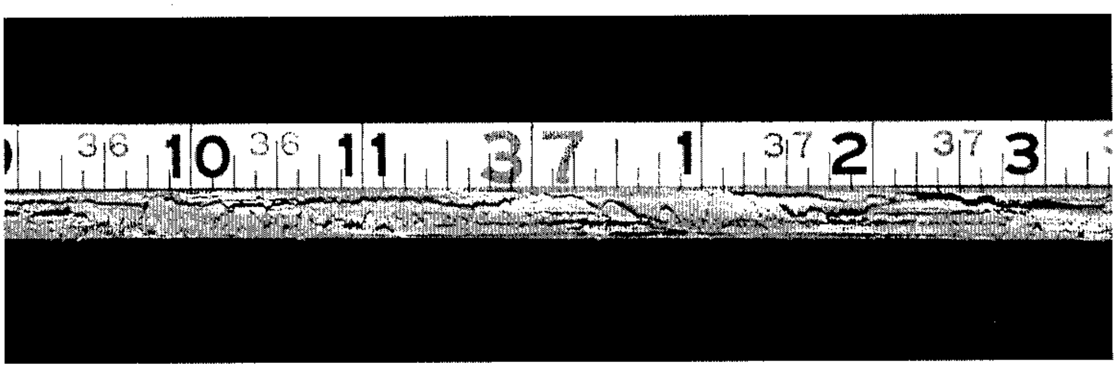
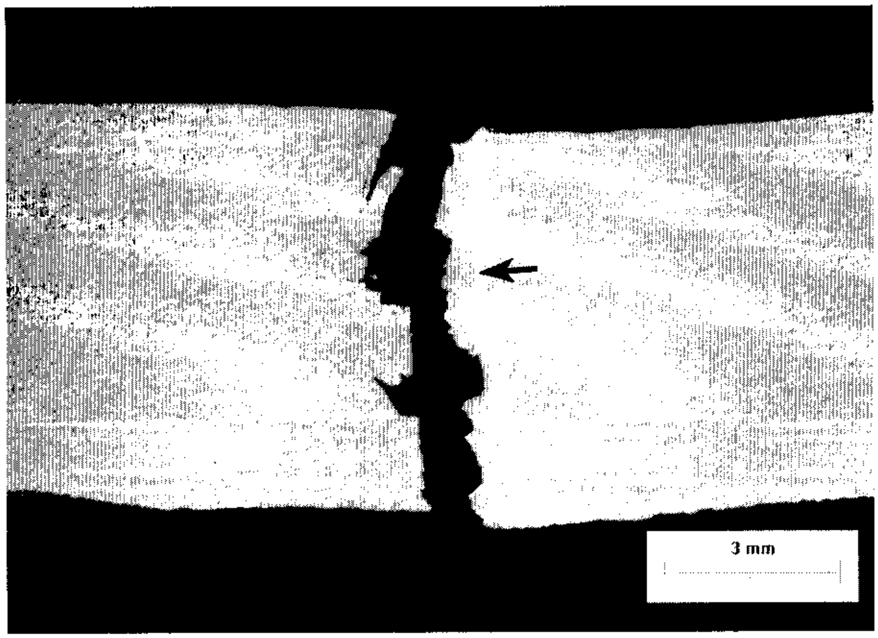


Figure 58 Joint No. 2753

Figure 57 shows a typical location with hook cracks and multilayer fracture surface, and Figure 58 is a closer view of part of the fracture.



Joint No. 2753 8X

Figure 59 Nital Etch

Matching transverse sections from the hook crack at the failure origin. The arrow indicates the weld line.

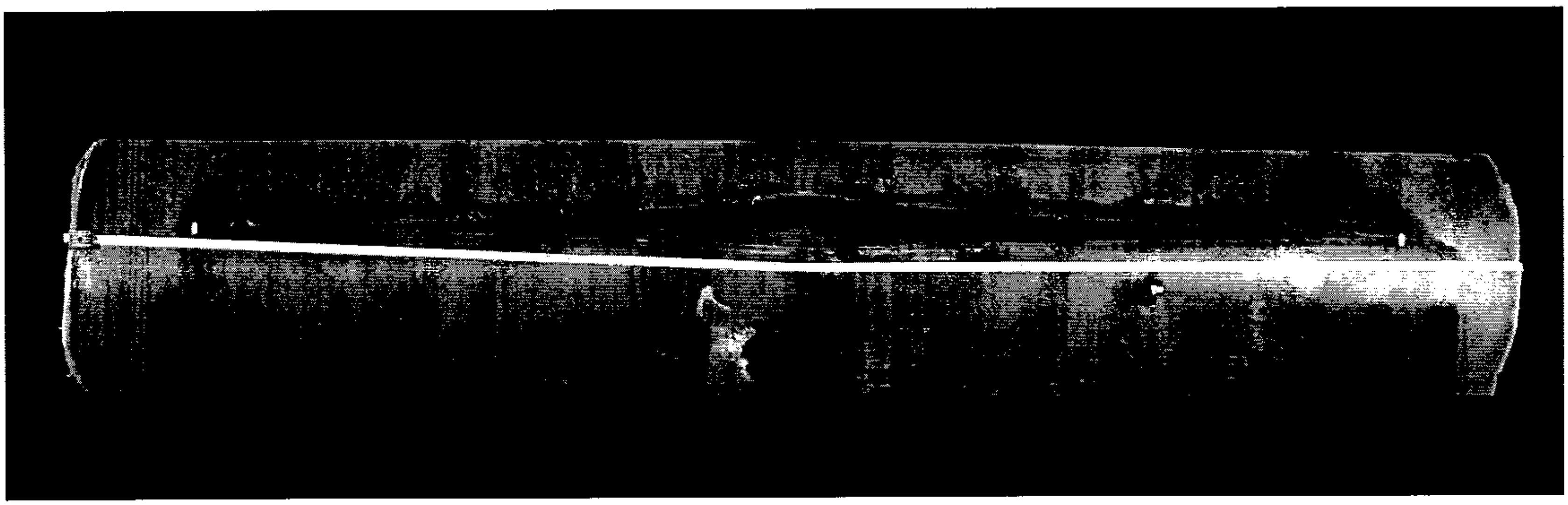


Figure 60 <u>Joint No. 4013</u>

Photograph of the rupture in Joint No. 4013.

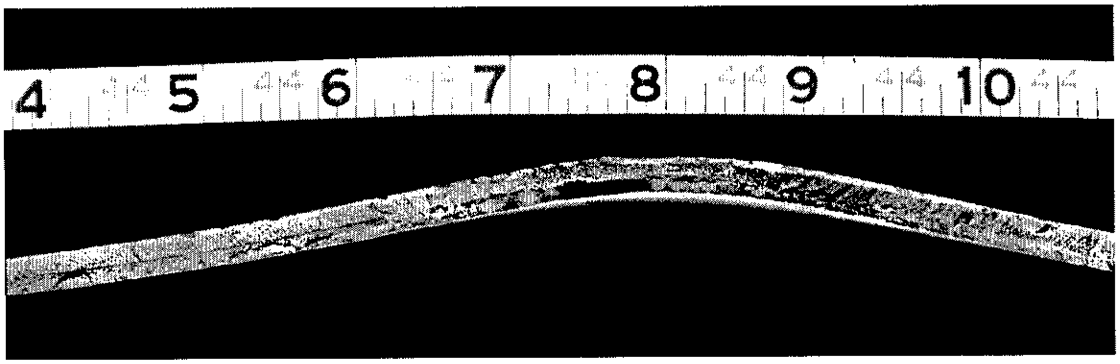


Figure 61 Joint No. 4013

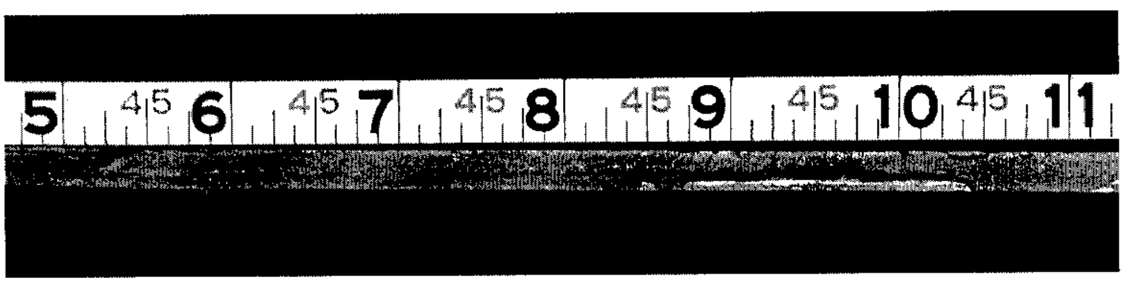
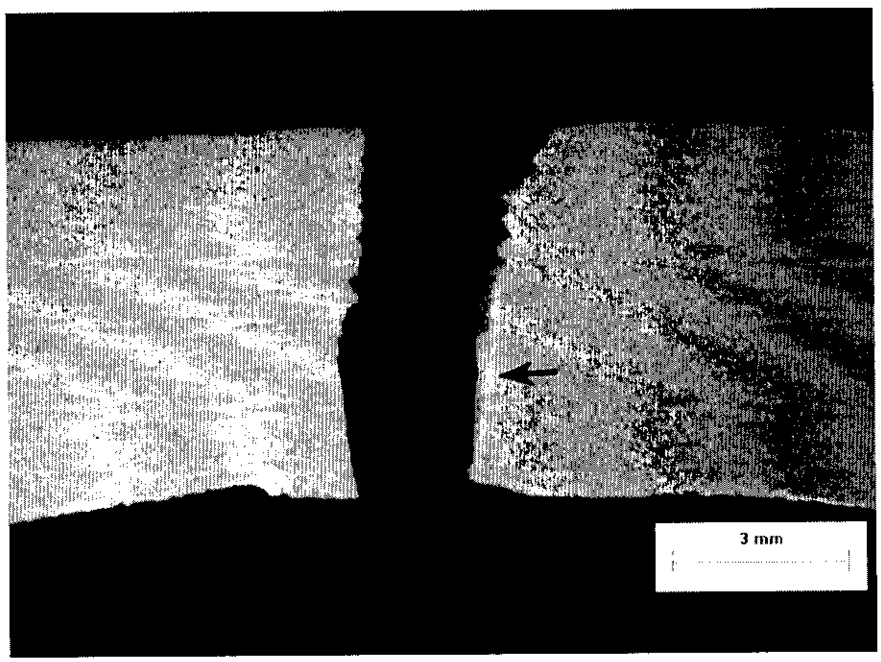


Figure 62 Joint No. 4013

Figure 61 shows a hook crack on the inside surface at the failure origin, and Figure 62 shows the fracture at the location of a reported USCD indication (45 feet, 7 inches).



Joint No. 4013 8X

Figure 63 Nital Etch

Matching transverse sections from the hook crack at the failure origin, with an arrow indicating the weld line.

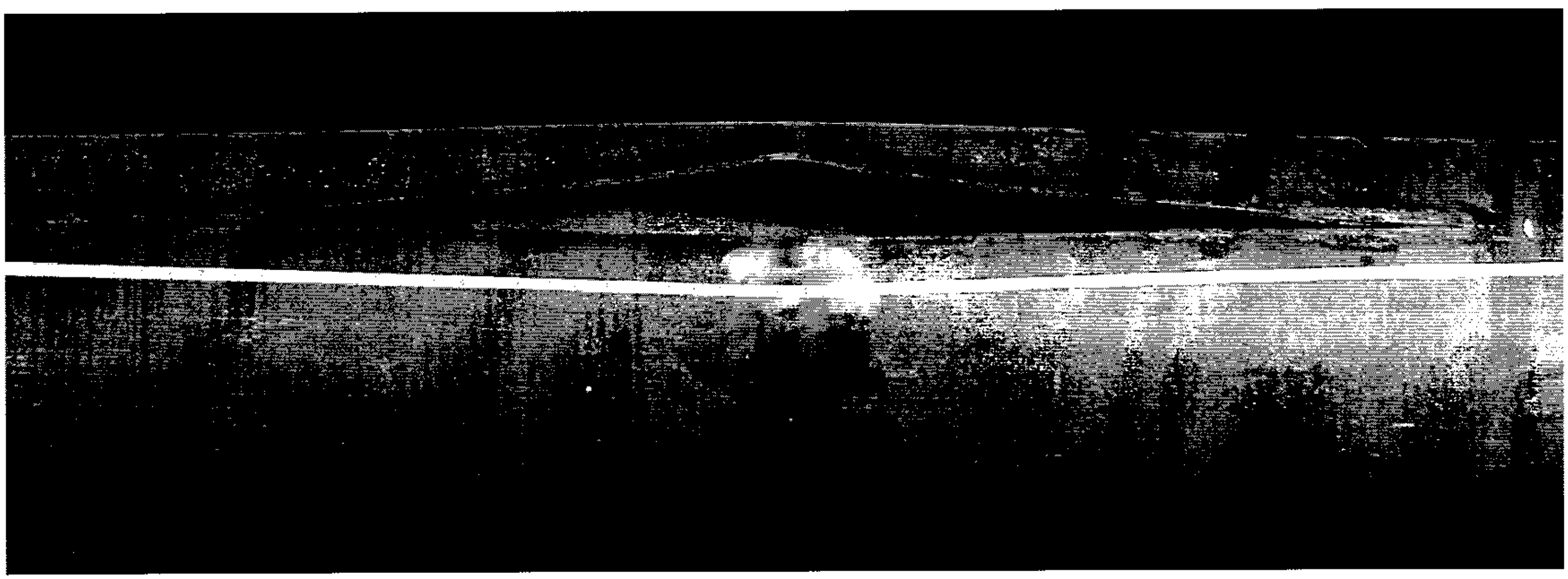


Figure 64 <u>Joint No. 6418</u>

Photograph showing the rupture in Joint No. 6418.

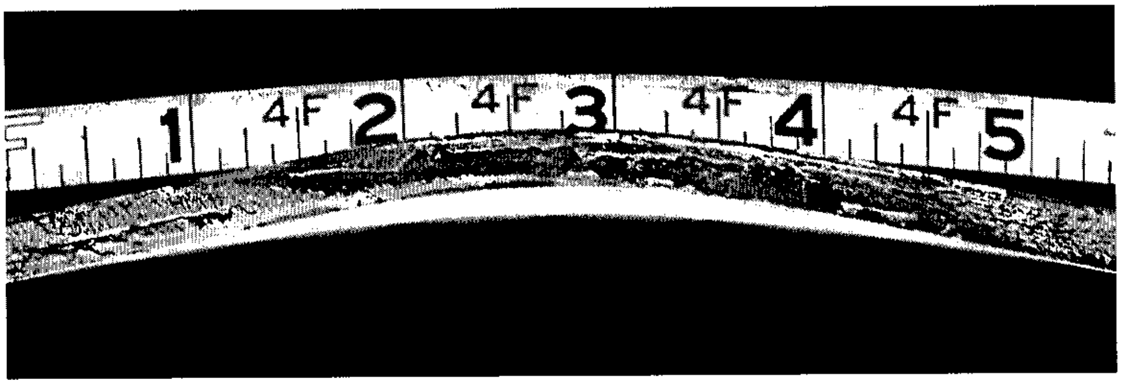


Figure 65 Joint No. 6418

Photograph of the apparent fracture origin.

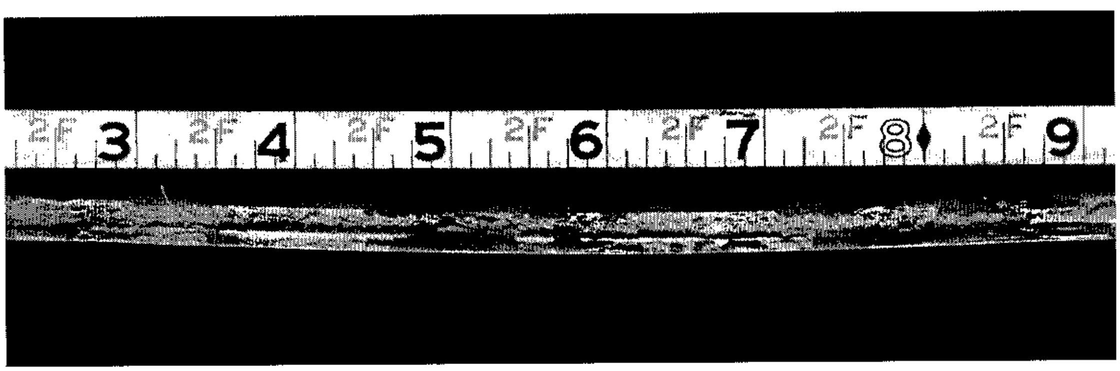
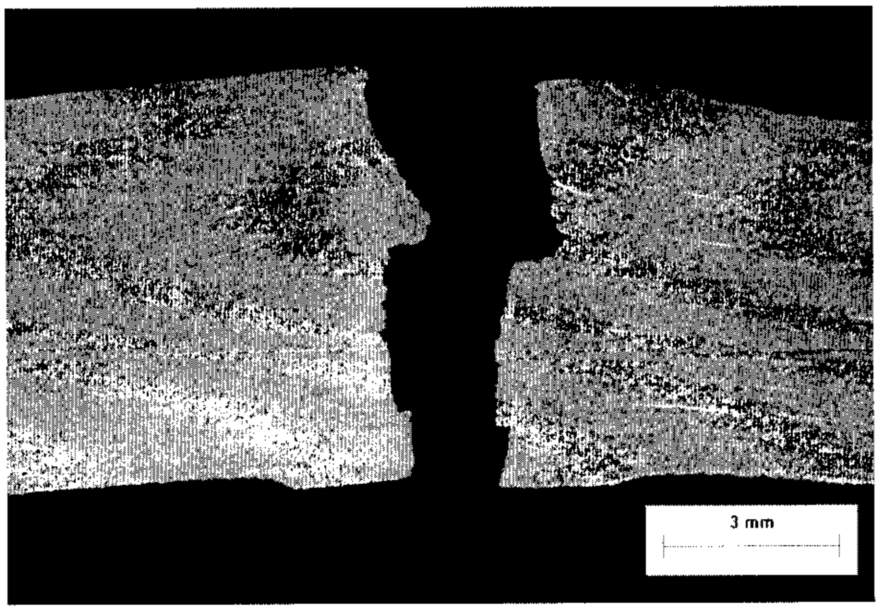


Figure 66 Joint No. 6418

Photograph showing a typical location with hook cracks and brittle fractures.



Joint No. 6418 8X

Figure 67 Nital Etch

Matching transverse sections from the hook crack at the failure origin.

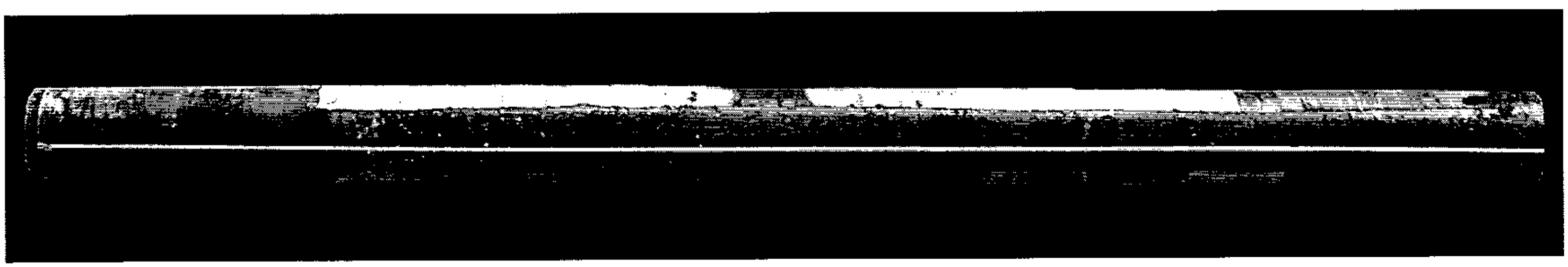


Figure 68 Joint No. 10737

Photograph showing the rupture in Joint 10737.

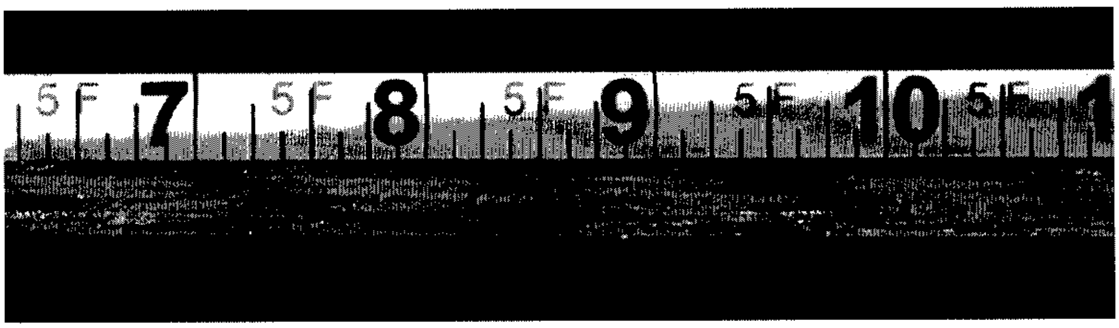


Figure 69 <u>Joint No. 10737</u>

Photograph of the fracture at the deepest flaw, which was in the middle of a long USCD reported indication.

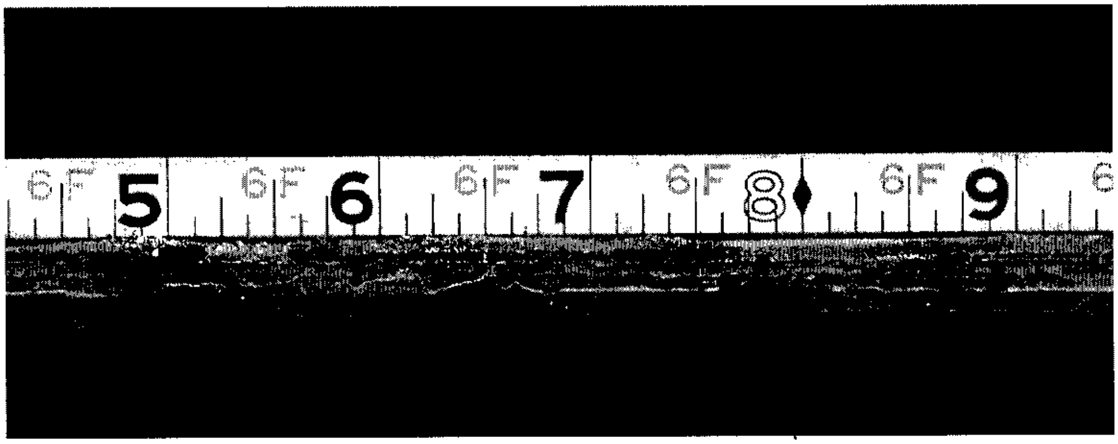


Figure 70 Joint No. 10737

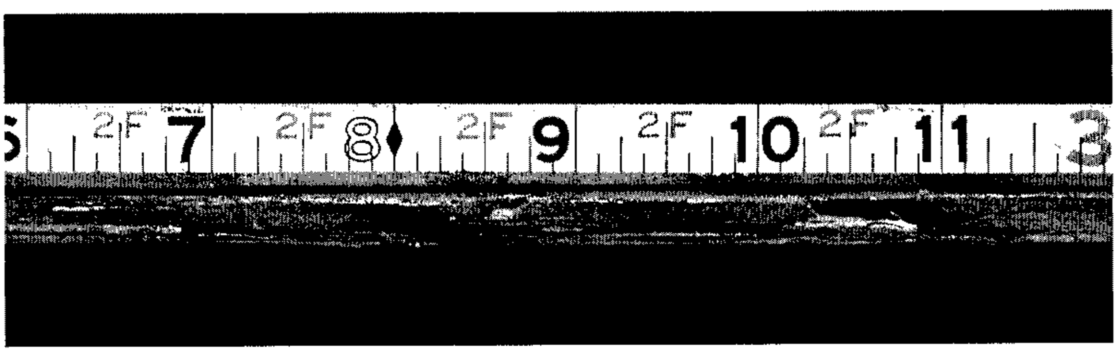
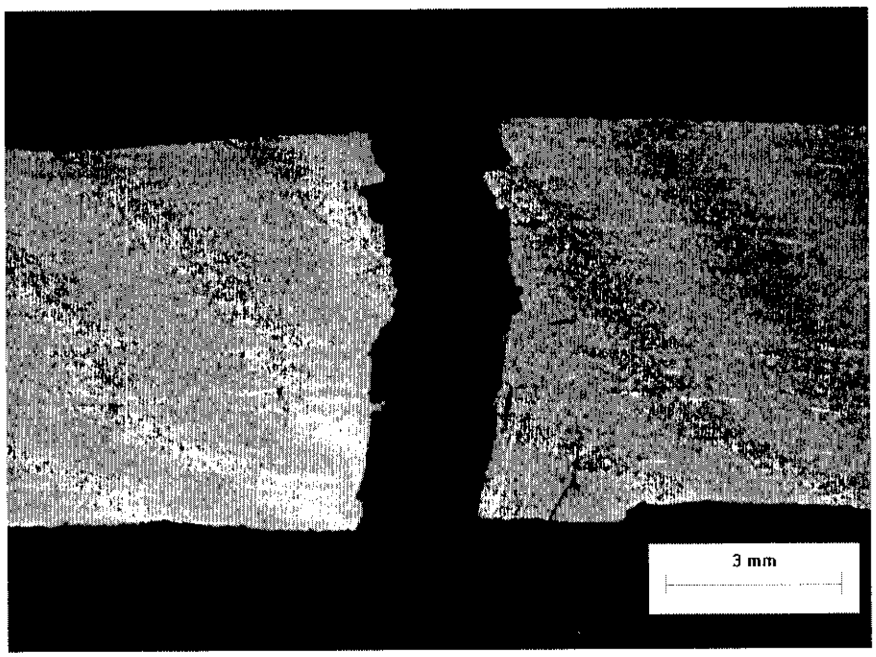


Figure 71 Joint No. 10737

Photographs showing hook cracks on the fracture surface at the other two reported USCD indications.



Joint No. 10737 8X

Figure 72 Nital Etch

Matching transverse sections from the hook crack shown in Figure 69.

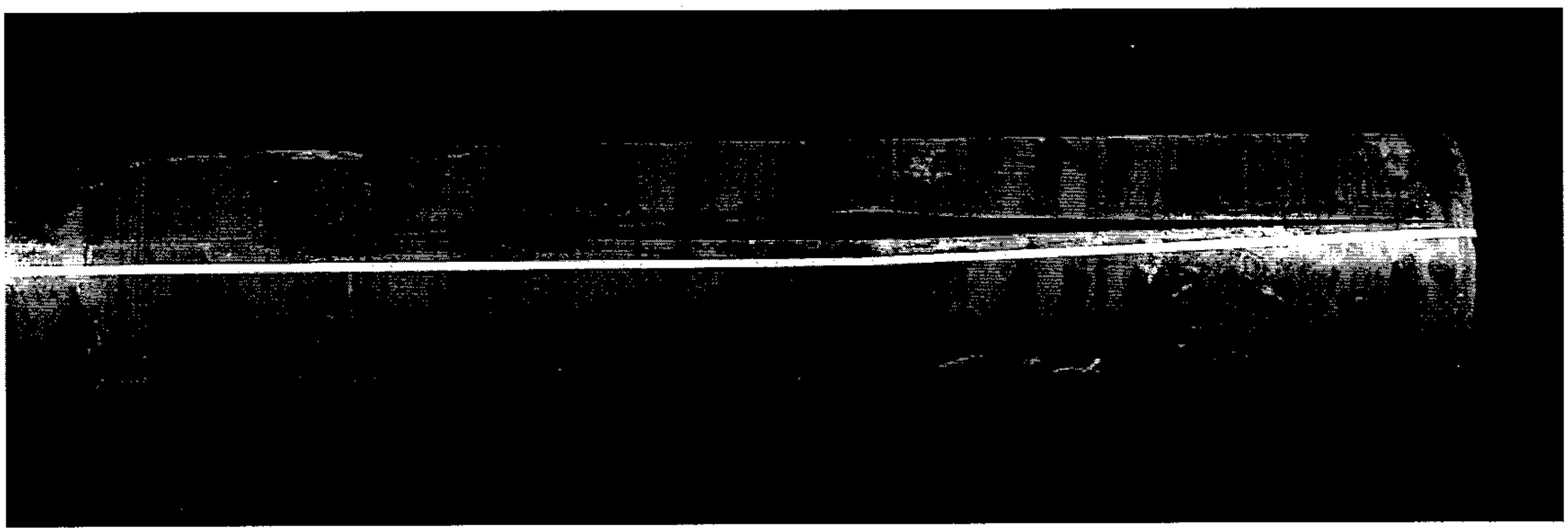


Figure 73 Joint No. 7757

Photograph showing the rupture in Joint No. 7757.

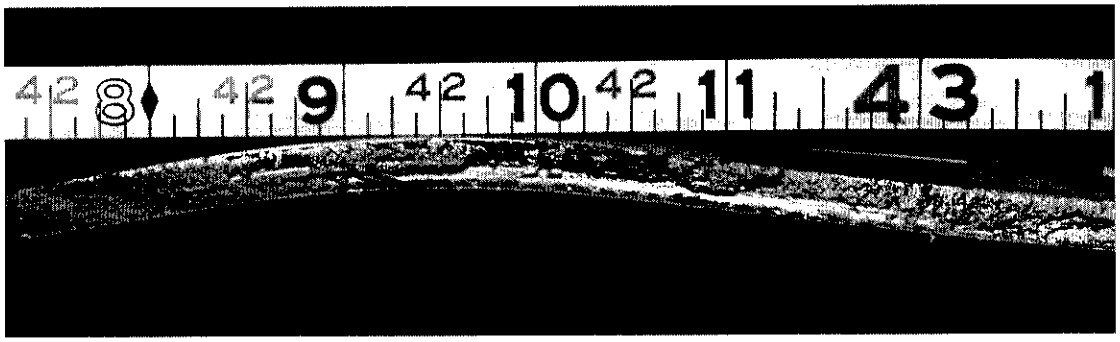


Figure 74 Joint No. 7757

Photograph showing the fracture at the failure origin.

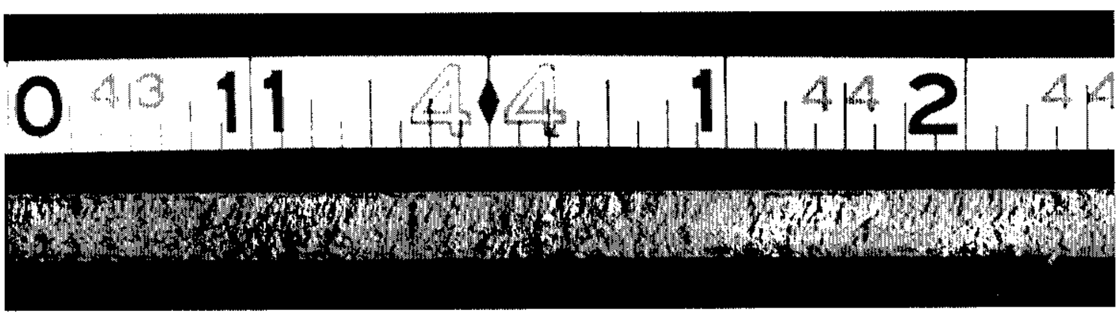
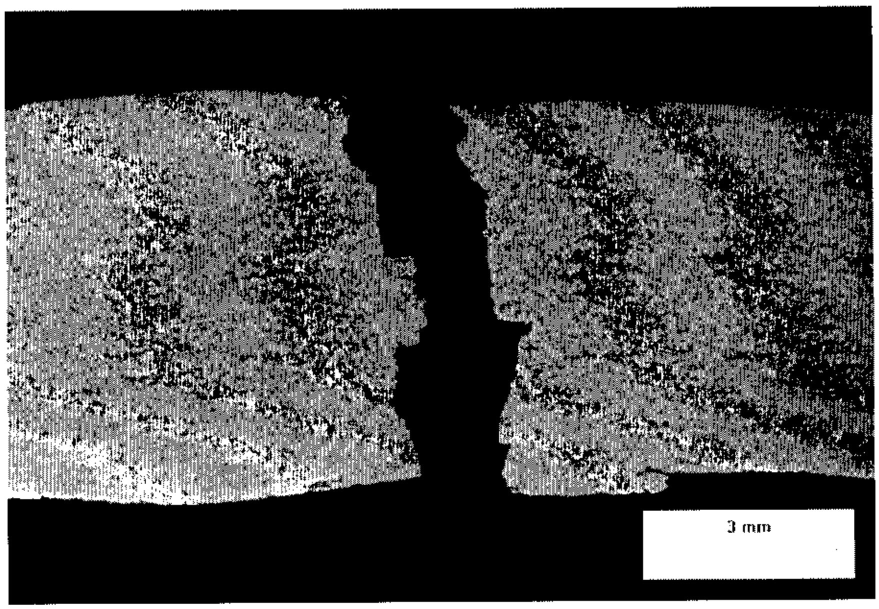


Figure 75 Joint No. 7757

Photograph showing a fracture area with black spots at the inside and stiching along the outside surface.



Joint No. 7757

8X

Figure 76

Nital Etch

Matching transverse sections from the fracture origin.

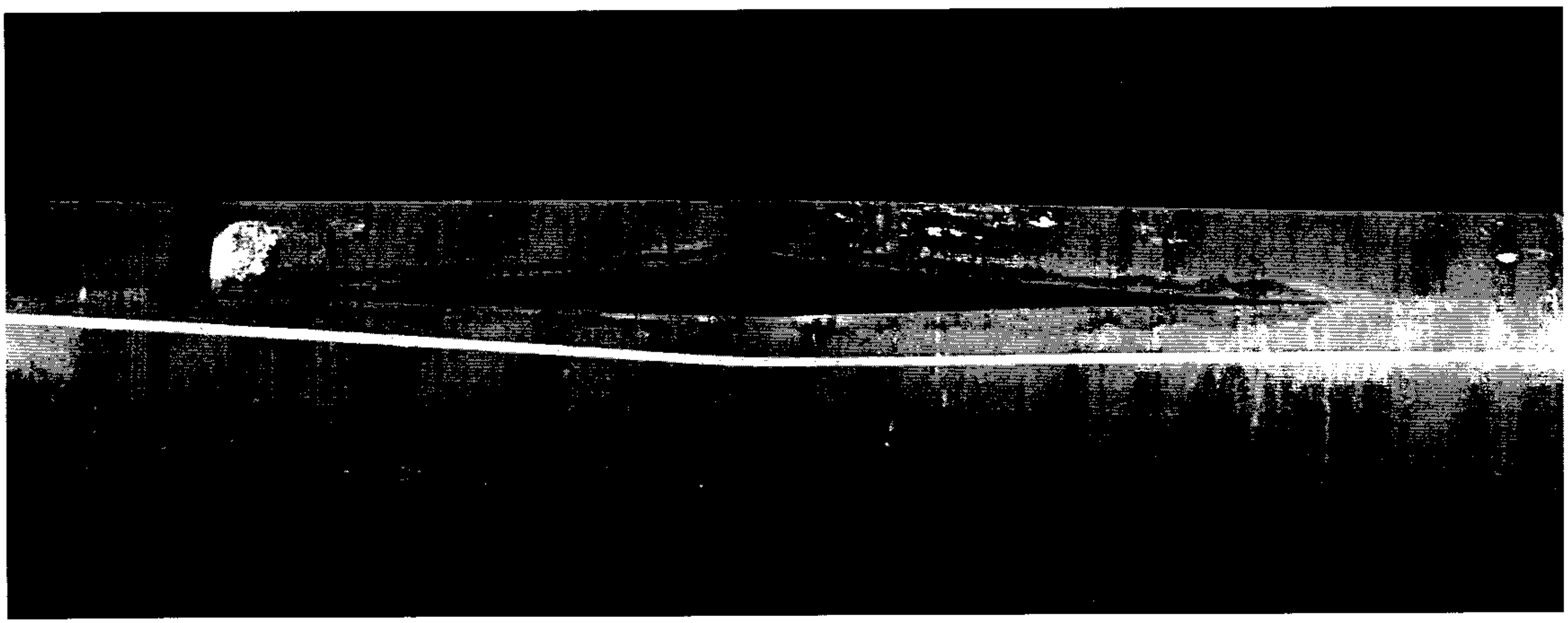


Figure 77 Joint No. 3897

Photograph showing the rupture in Joint No. 3897.

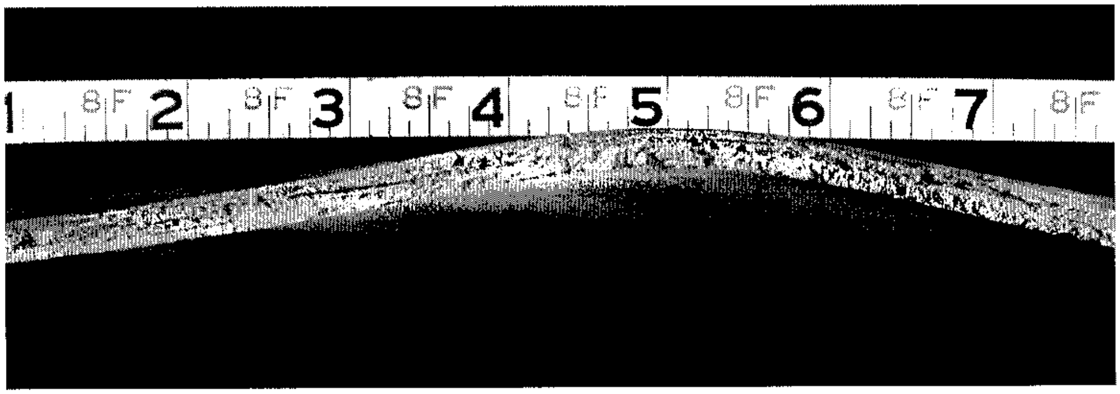


Figure 78 Joint No. 3897

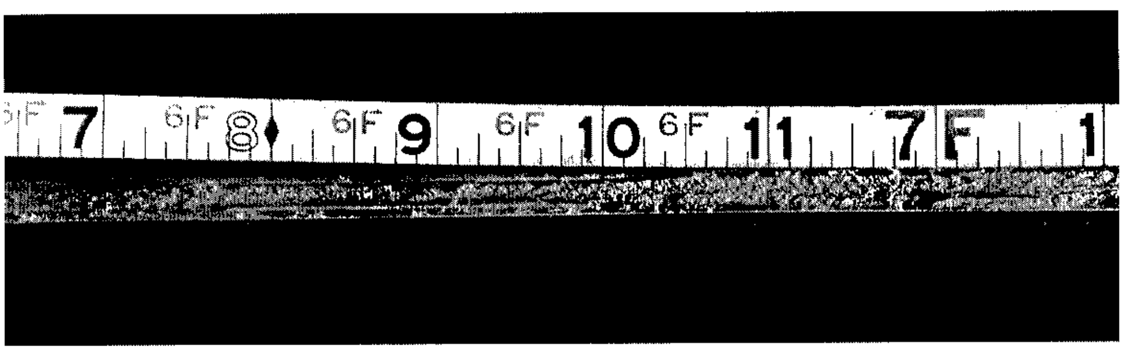
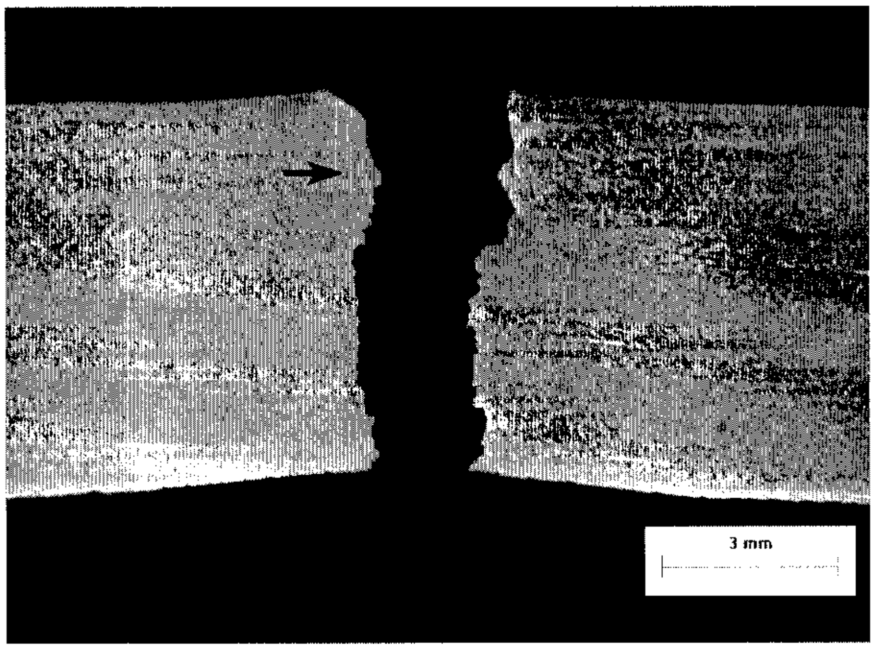


Figure 79 Joint No. 3897

Figure 78 shows the fracture at the failure origin, and Figure 79 shows a typical area of brittle fracture and hook cracks.



Joint No. 3897 8X

Figure 80 Nital Etch

Matching transverse sections from the failure origin, with an arrow indicating the weld line.

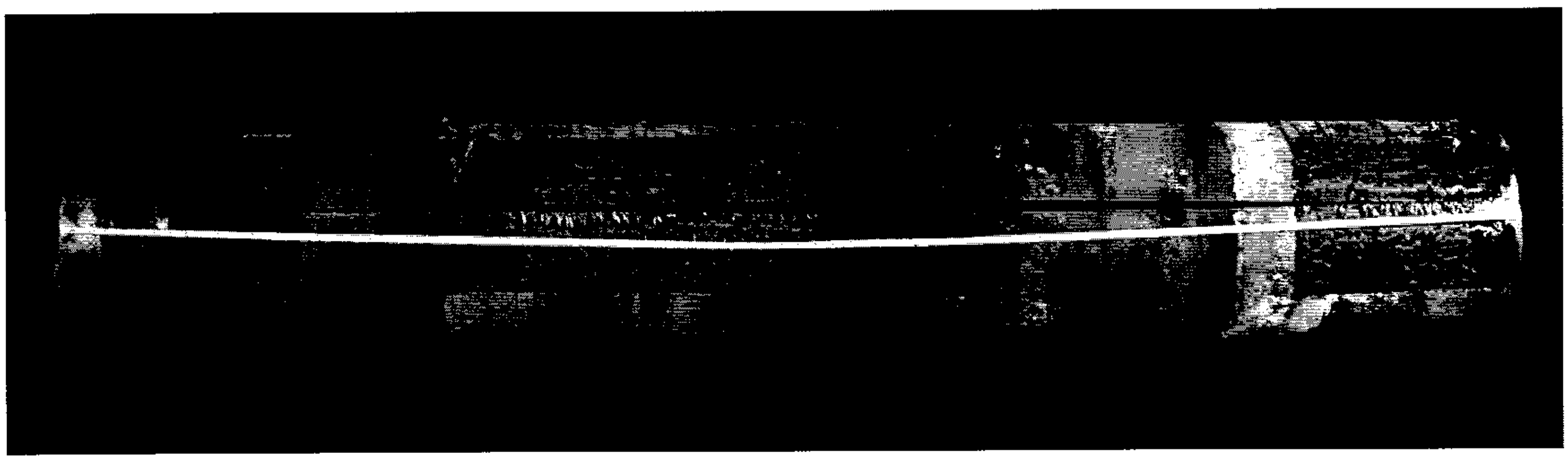


Figure 81 Joint No. 5204

Photograph showing the rupture in Joint No. 5204.

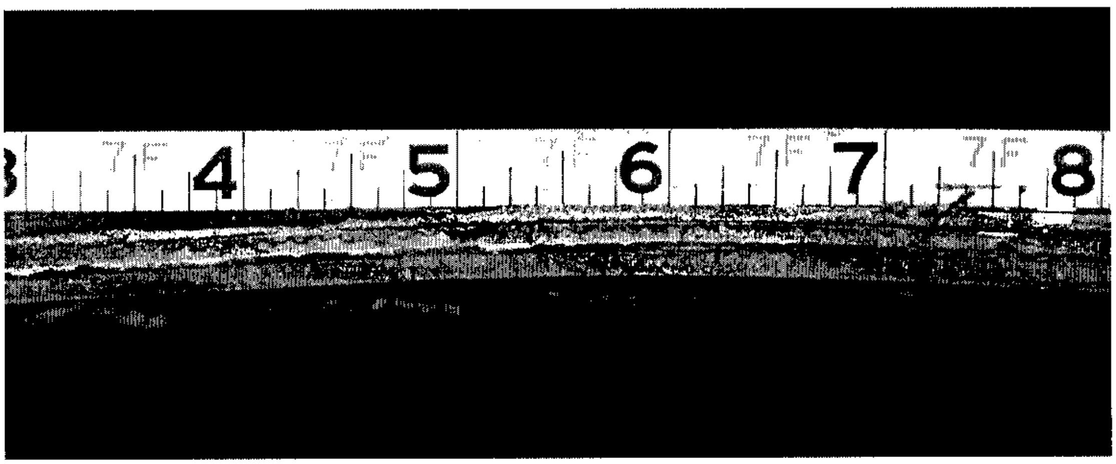
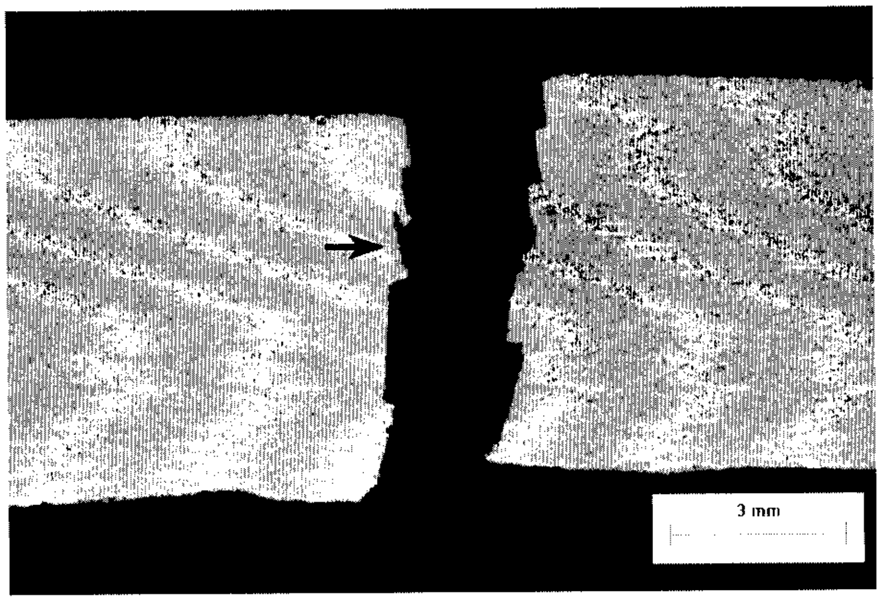


Figure 82 <u>Joint No. 5204</u>

Photograph showing the deepest flaw, which was a hook crack.



Joint No. 5204

8X

Figure 83

Nital Etch

Matching transverse sections from the hook crack.

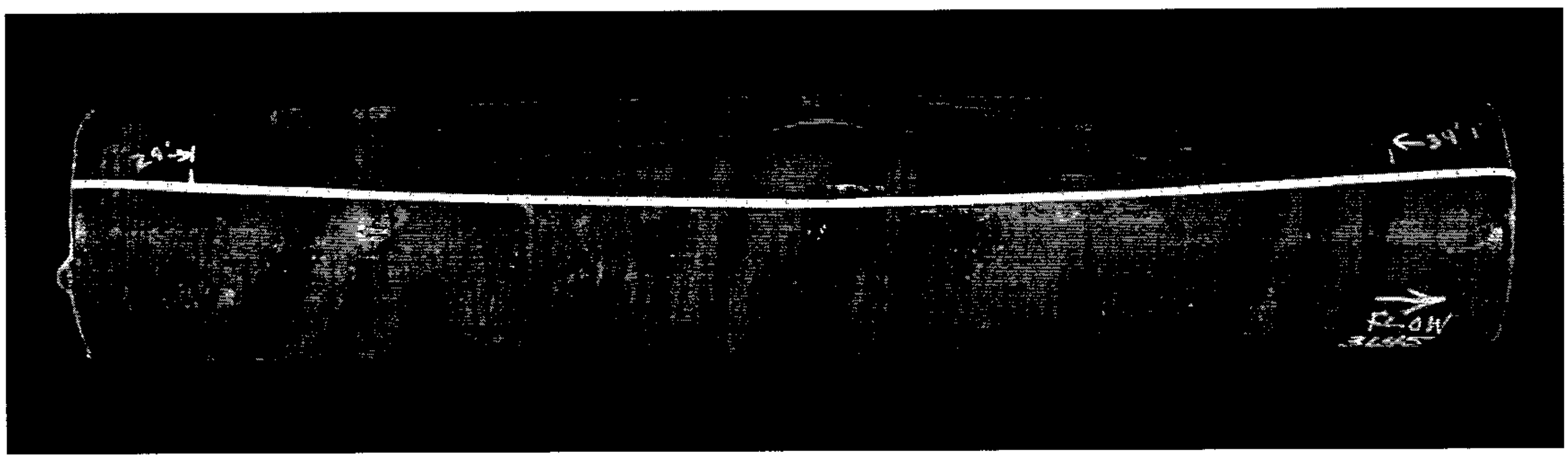


Figure 84 Joint No. 3645

Photograph of the rupture in Joint No. 3645.

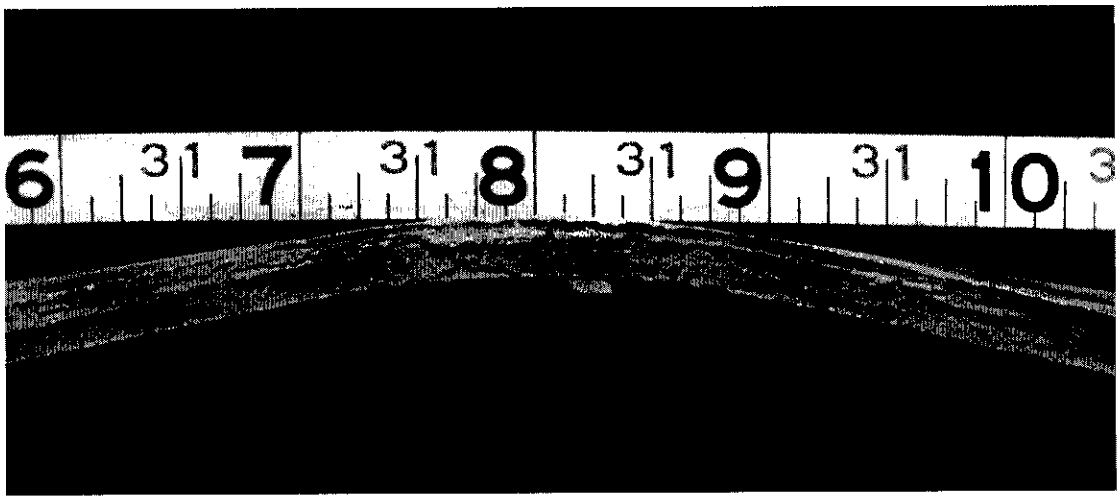


Figure 85 Joint No. 3645

Photograph of a hook crack at the outside surface at the failure origin.

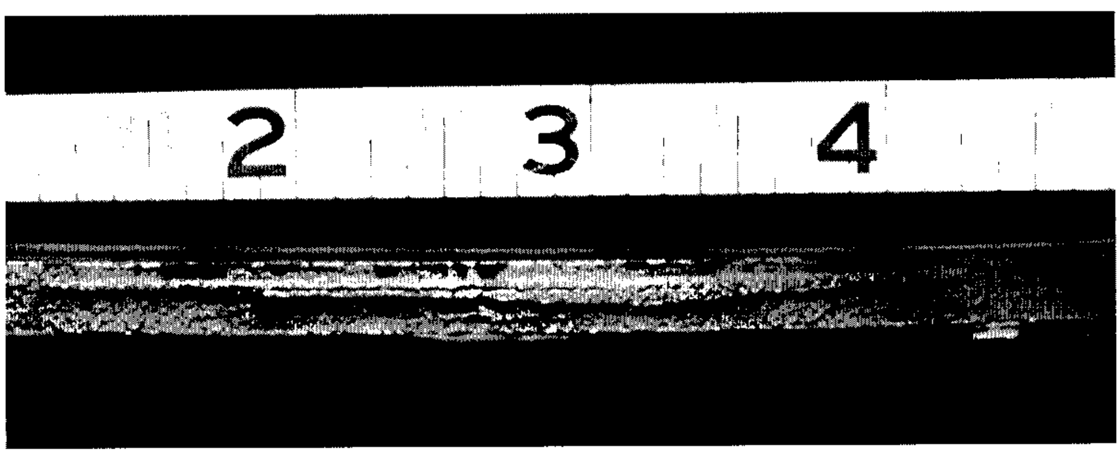
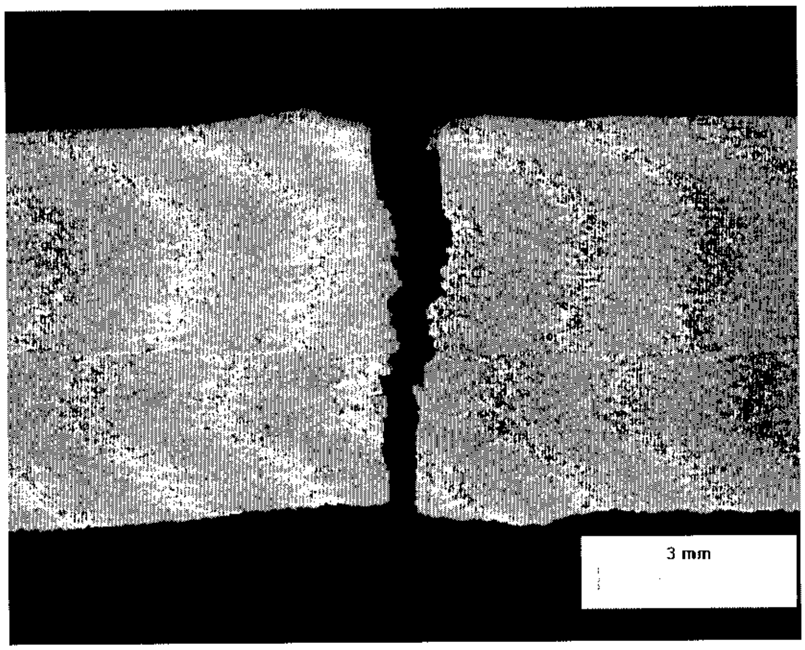


Figure 86 Joint No. 3645

Photograph of the fracture surface at the deepest flaw.



<u>Joint No. 3645</u> 8X

Figure 87 Nital Etch

Matching transverse sections from the failure origin. There was minor mechanical damage at the outside surface.

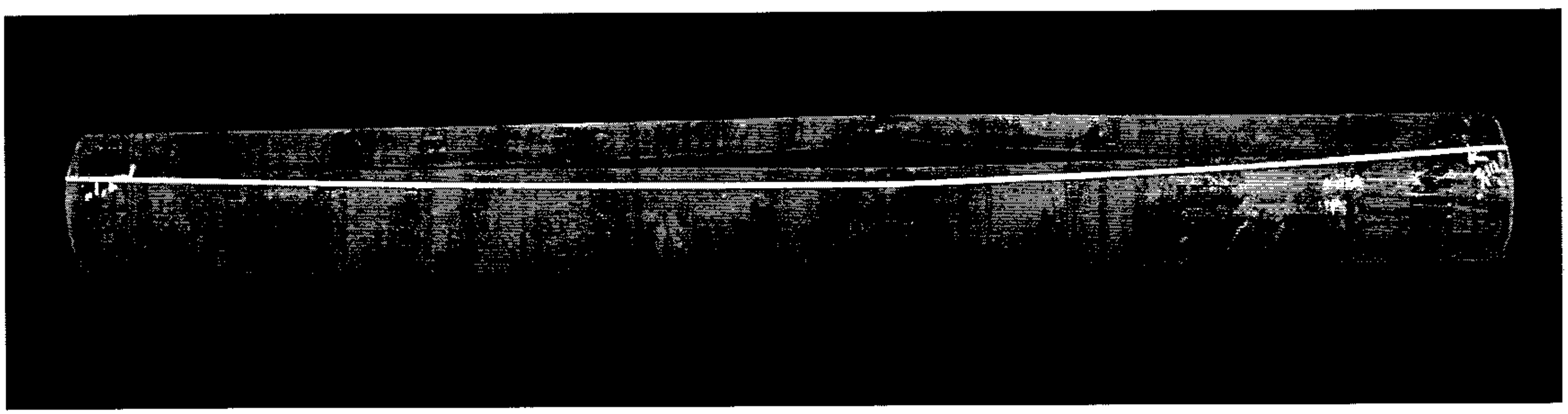


Figure 88 <u>Joint No. 332</u>

Photograph showing the rupture in Joint No. 332.

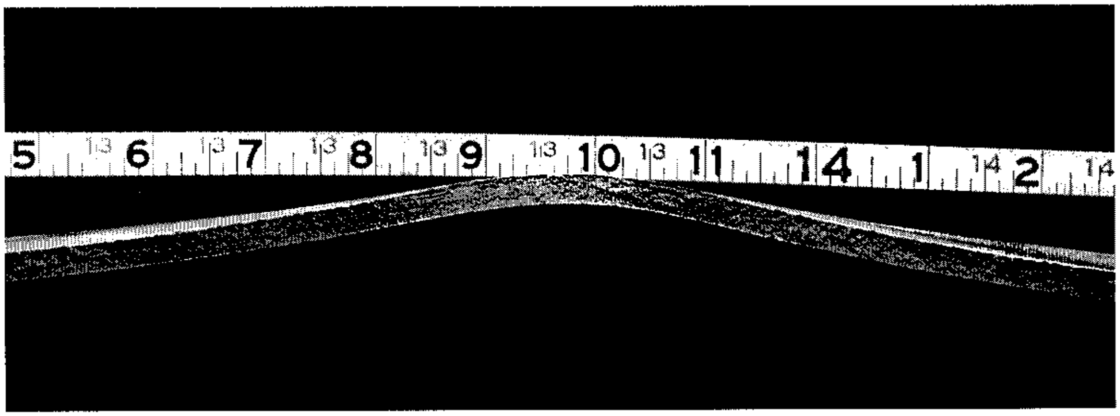


Figure 89 Joint No. 332

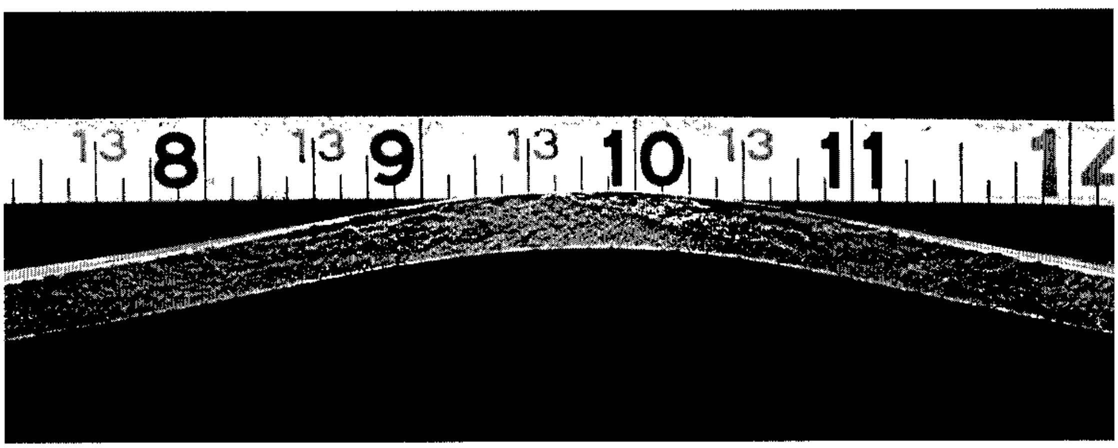
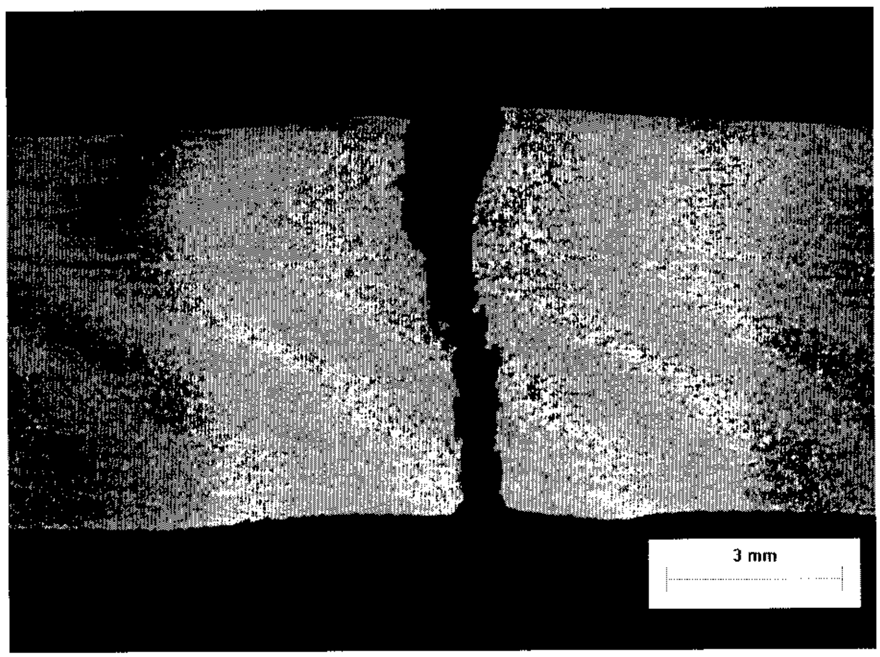


Figure 90 Joint No. 332

Figure 89 shows chevrons pointing toward the failure origin, and Figure 90 is a closer view of the origin.



Joint No. 332 8X

Figure 91 Nital Etch

Matching sections from the failure origin.

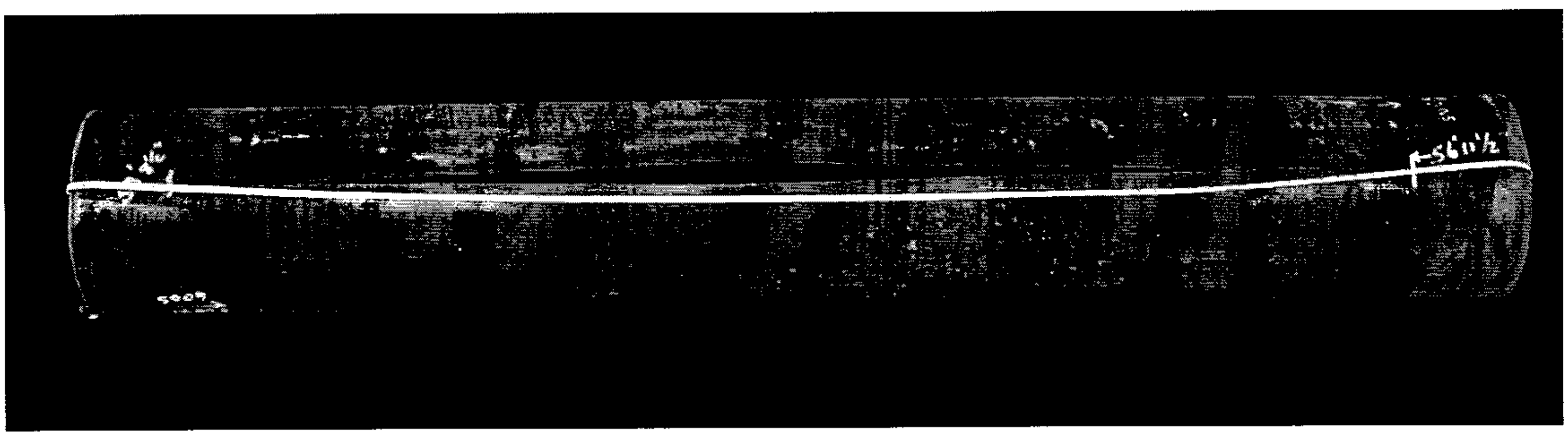


Figure 92 Joint No. 6005

Photograph showing the rupture in Joint No. 6005.

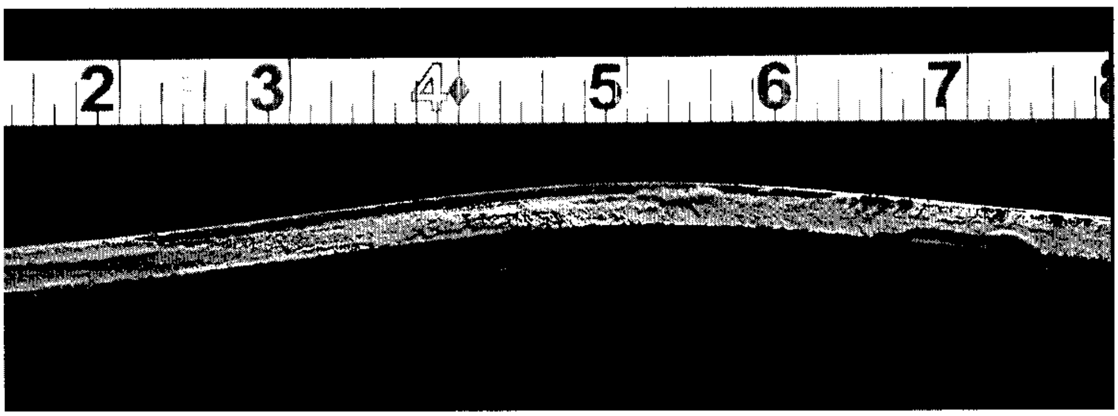
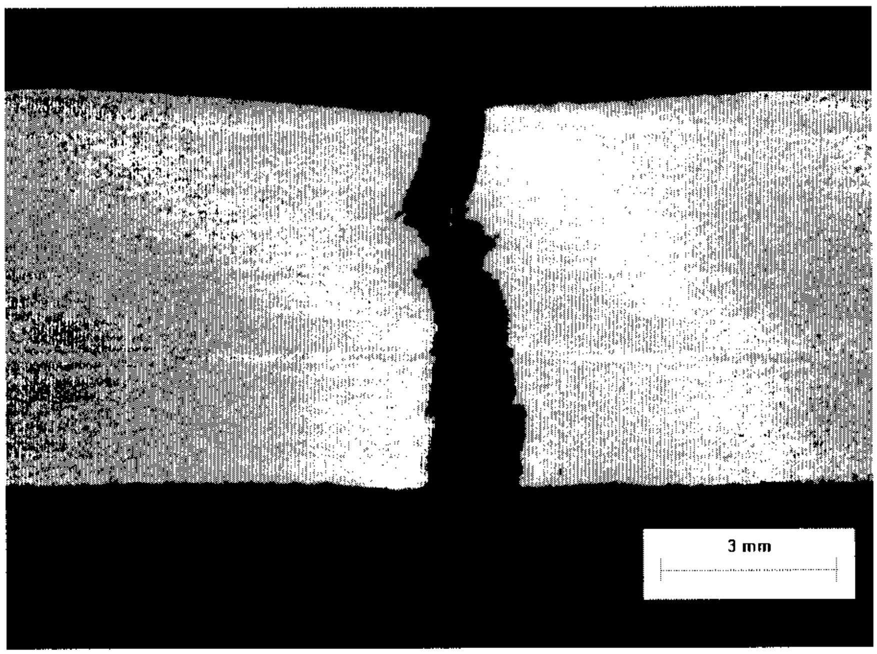


Figure 93 <u>Joint No. 6005</u>

Photograph showing a hook crack at the fracture origin.



Joint No. 6005 8X

Figure 94 Nital Etch

Matching transverse sections from the fracture origin.

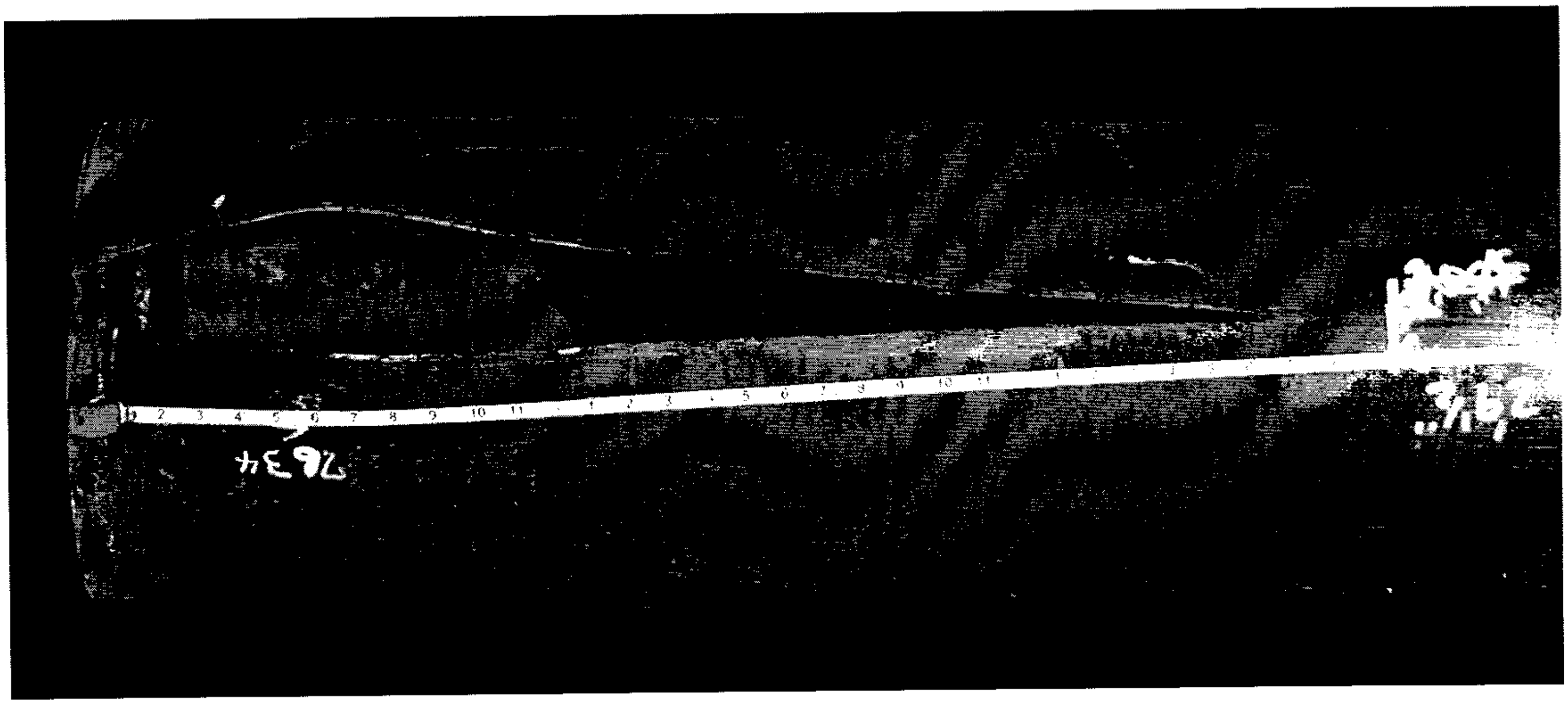


Figure 95 <u>Joint No. 7634</u>

Photograph showing the rupture in Joint No. 7634.

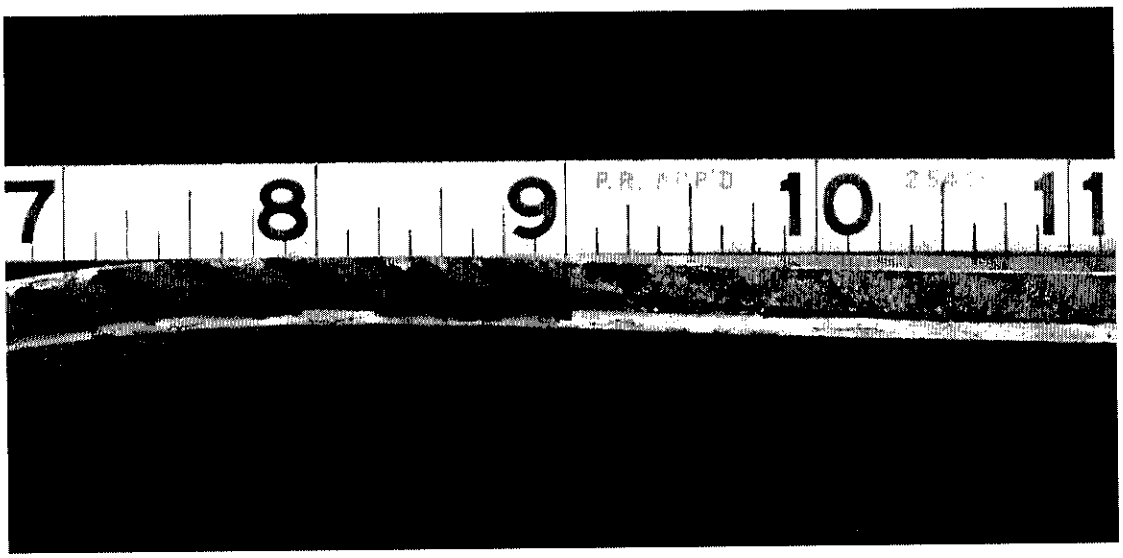
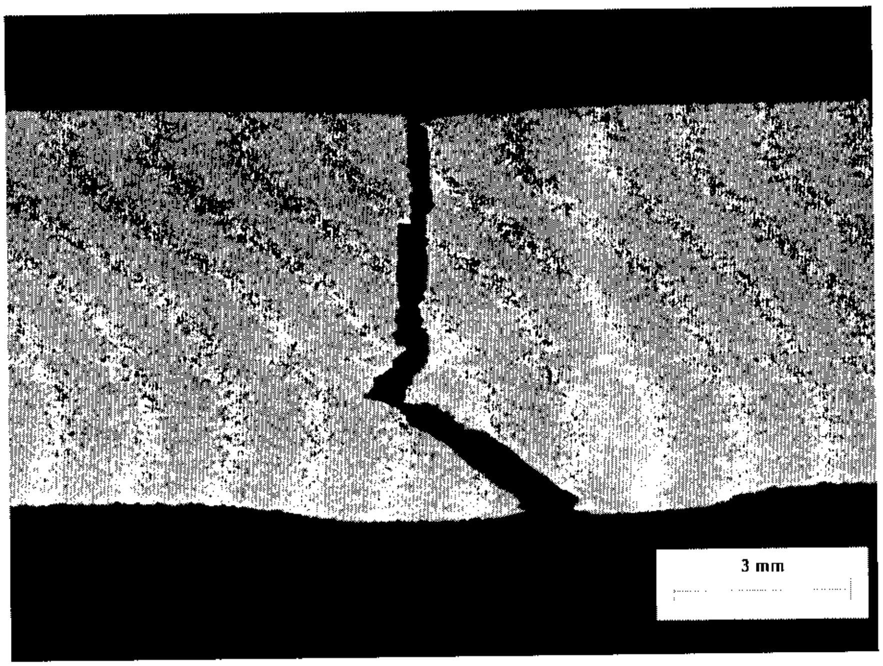


Figure 96 <u>Joint No. 7634</u>

Photograph showing a large hook crack at the fracture origin.



Joint No. 7634

8X
Nital Etch

Figure 97

Matching transverse sections from the hook crack at the fracture origin.

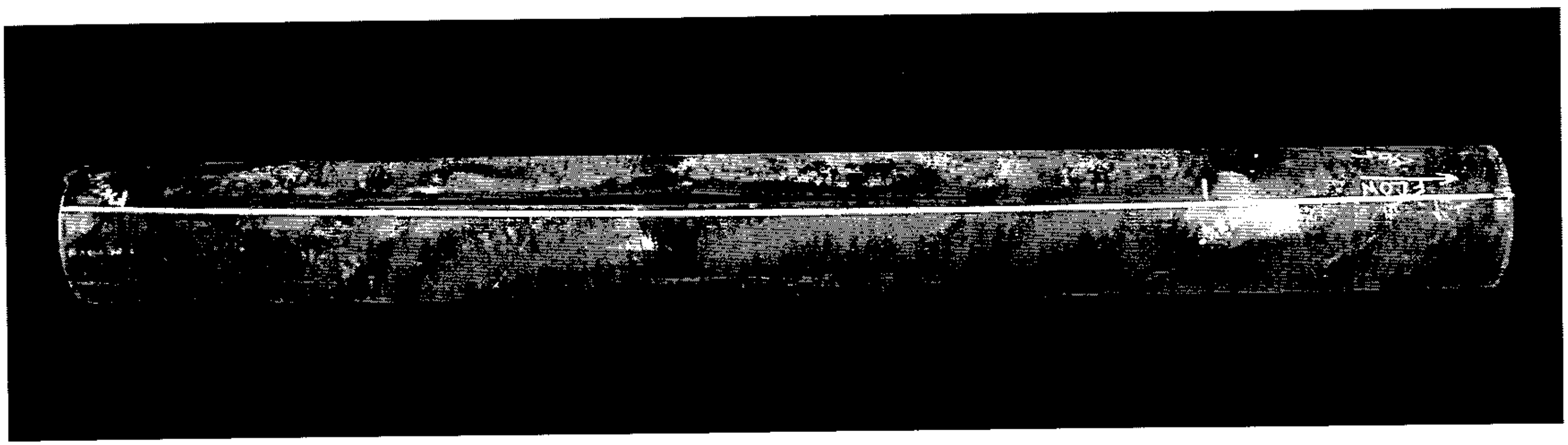


Figure 98 <u>Joint No. 2405</u>

Photograph showing the rupture in Joint No. 2405.

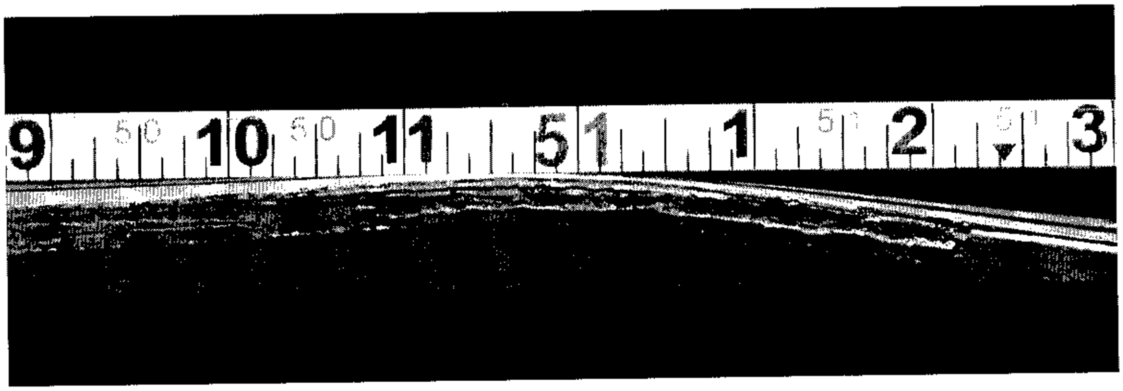


Figure 99 Joint No. 2405

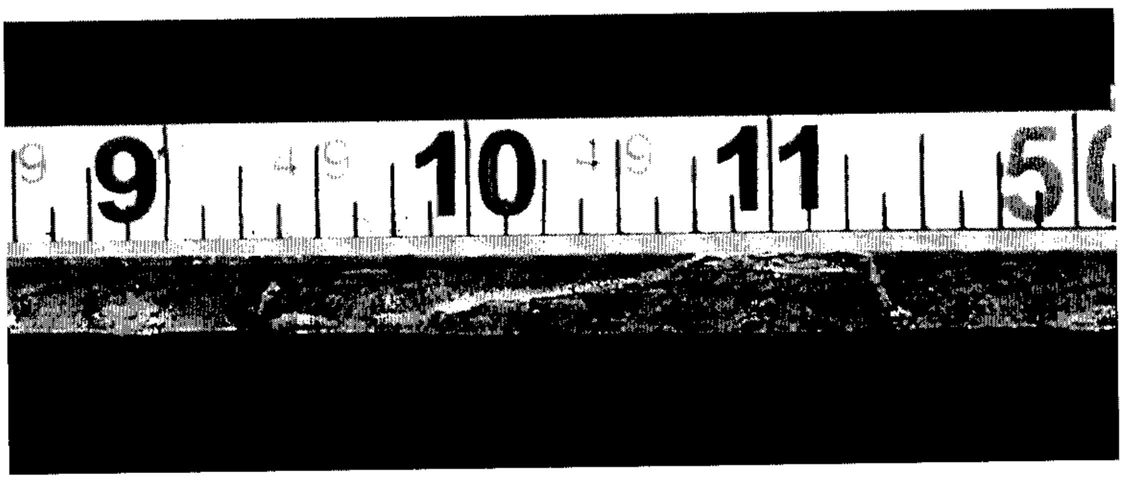
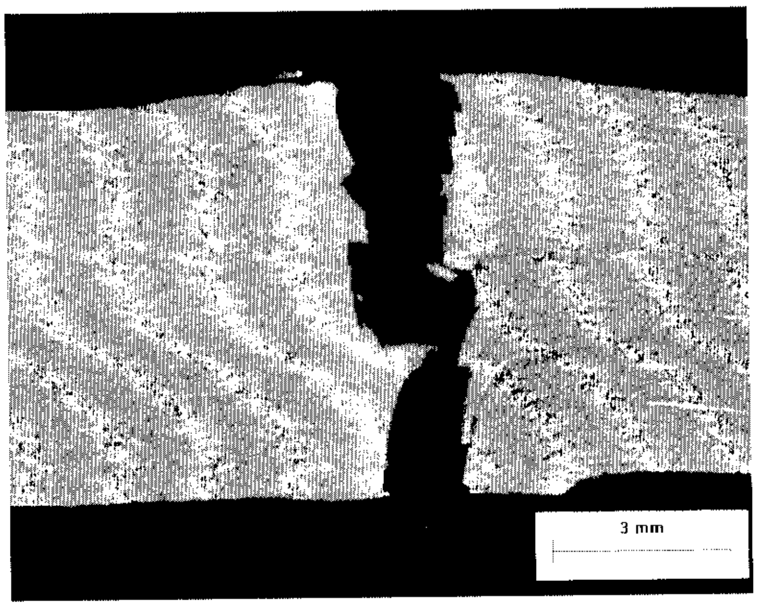


Figure 100 Joint No. 2405

Figure 99 shows the deepest flaw and likely failure origin, and Figure 100 shows part of a hook crack within the length of a reported USCD indication.



Joint No. 2405 8X

Figure 101 Nital Etch

Matching transverse sections from the hook crack at the suspected failure origin.

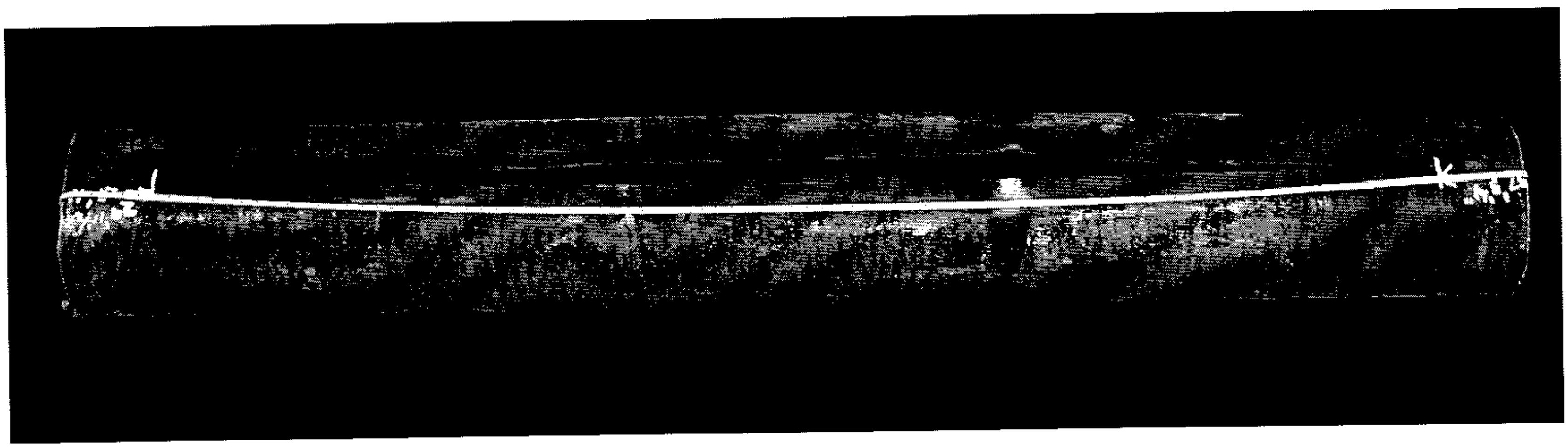


Figure 102 Joint No. 386

Photograph showing the rupture in Joint No. 386.

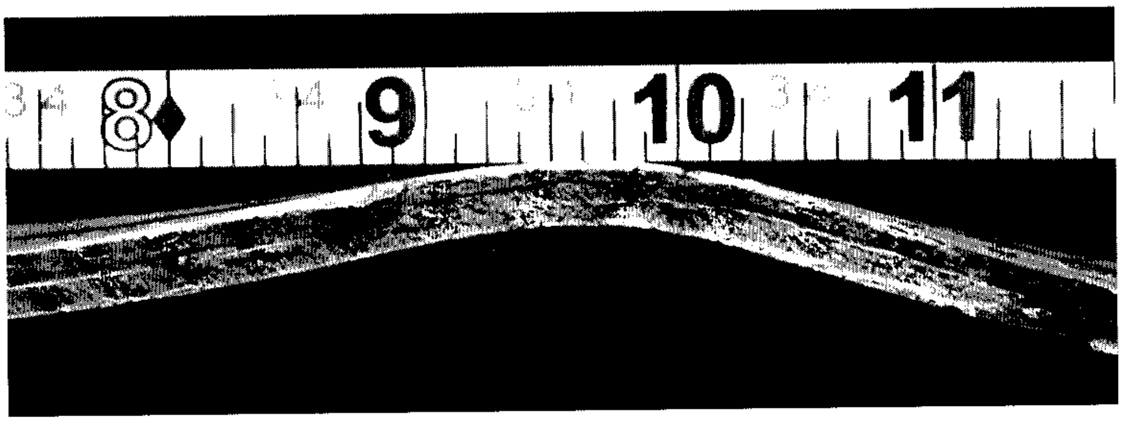
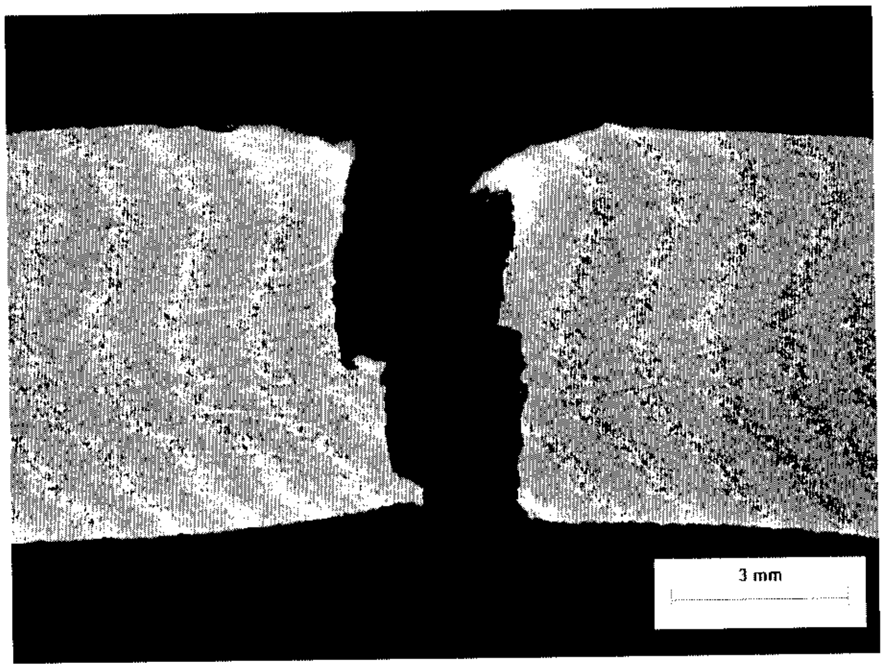


Figure 103 Joint No. 386

Photograph showing a hook crack at the likely failure origin.



Joint No. 386 8X

Figure 104 Nital Etch

Matching transverse sections from the failure origin. The outside surface was mechanically damaged.

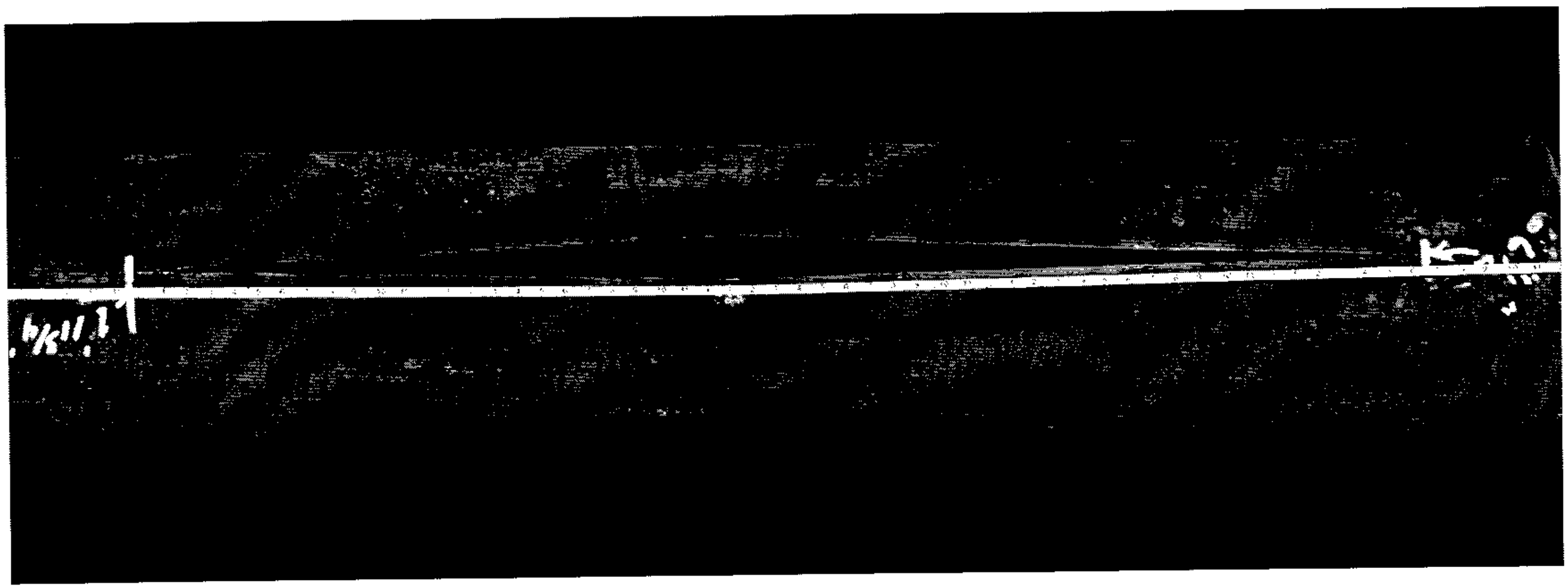


Figure 105 Joint No. 8769

Photograph showing the rupture in Joint No. 8769.

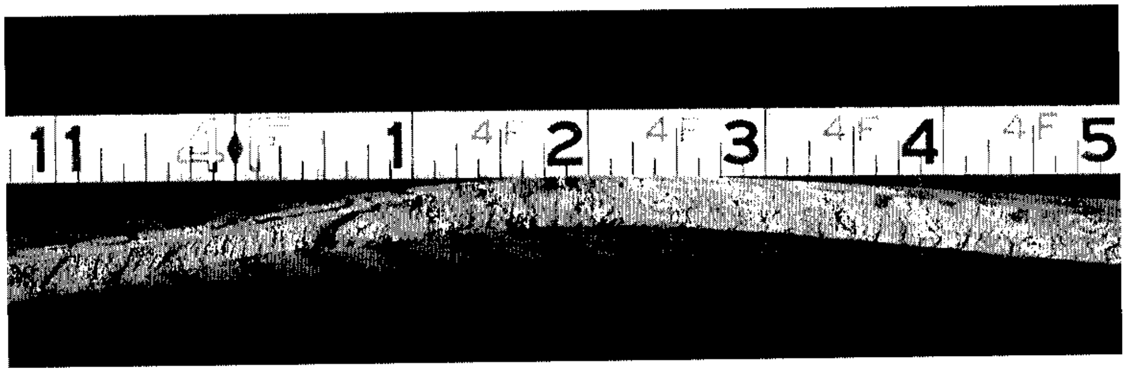


Figure 106 Joint No. 8769

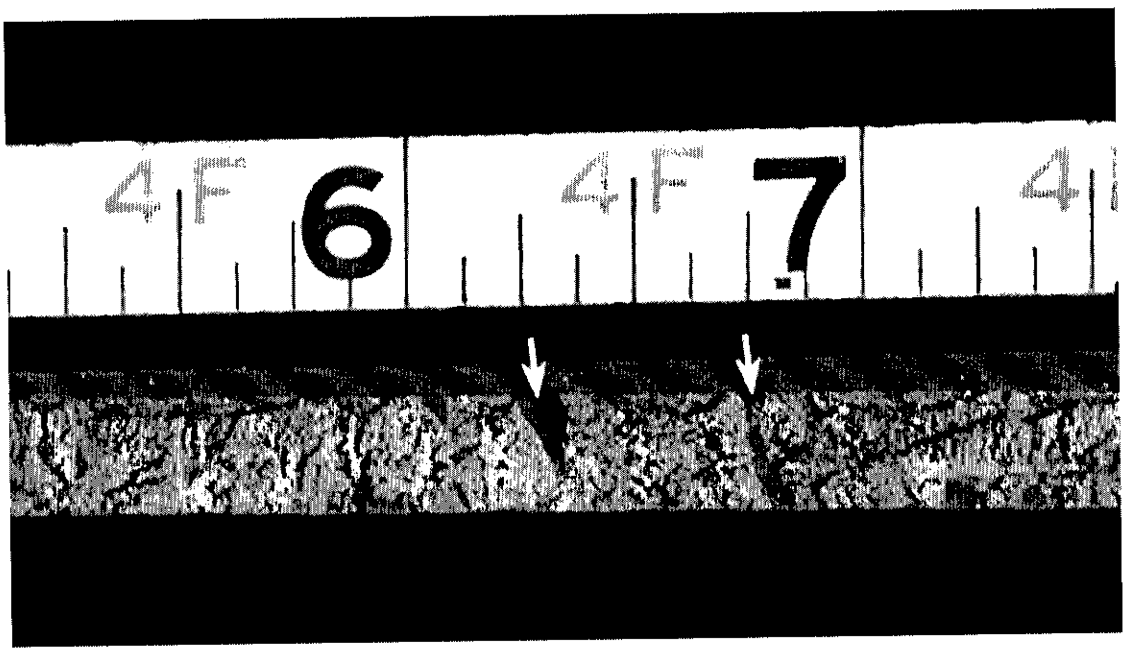
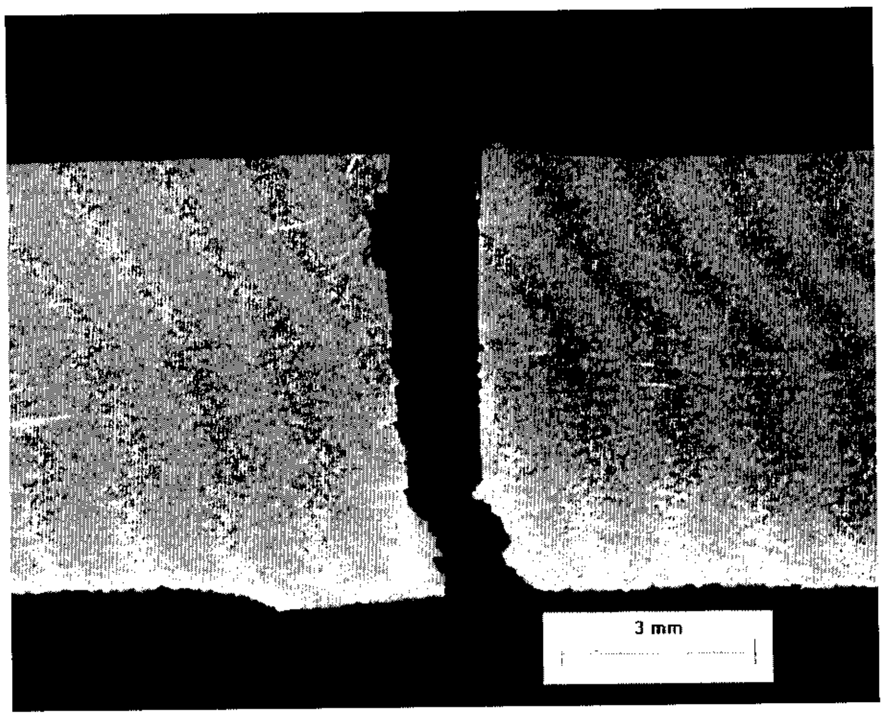


Figure 107 Joint No. 8769

Figure 106 shows a hook crack, multilayered fracture and black spots at a bulge near the center of the rupture, and Figure 107 shows the deepest flaws, arrows, found along the rupture.



Joint No. 8769

8X
Nital Etch

Figure 108

Matching transverse sections from the black spots indicated by the arrow at left in Figure 107.

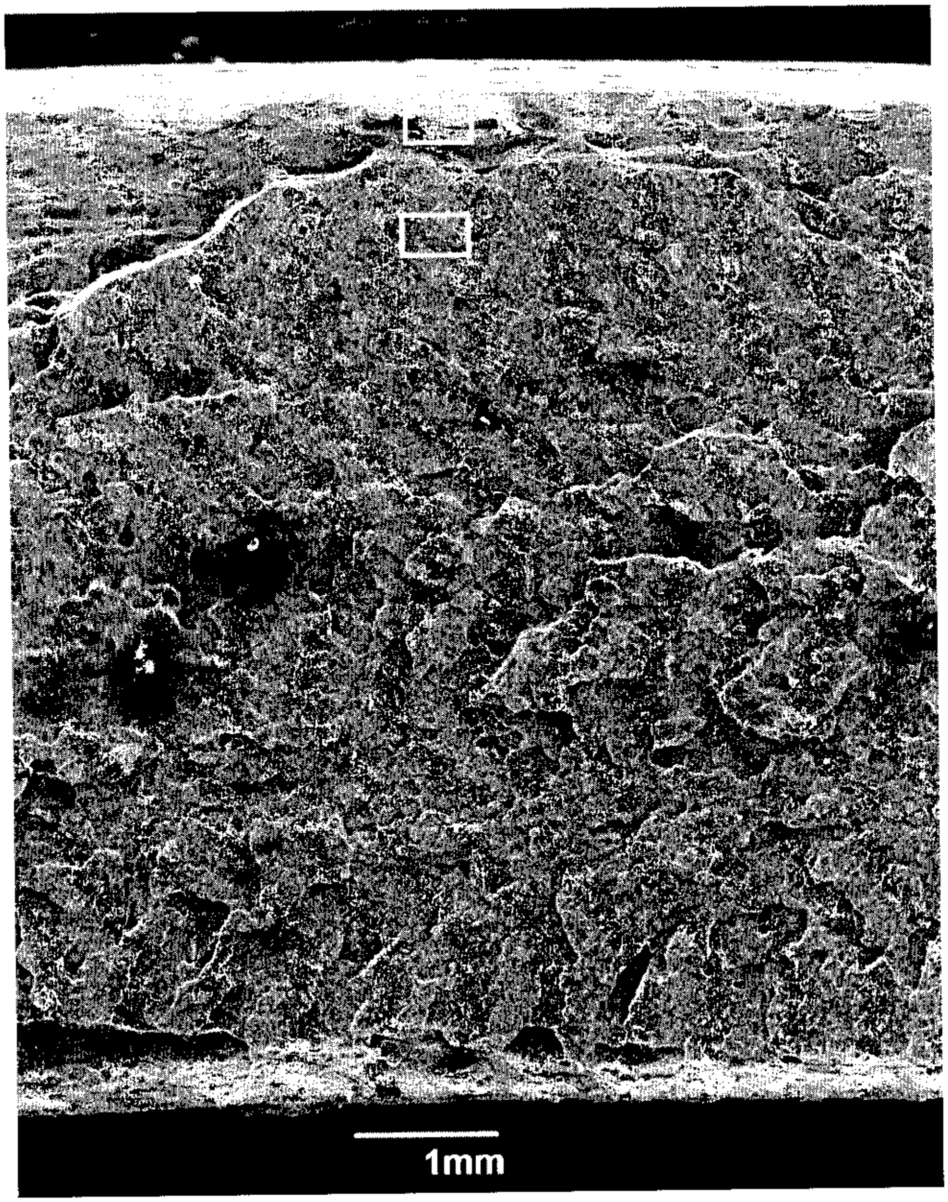


Figure 109 Joint No. 332 18X

Macrograph of the failure origin of Joint No. 332. The boxes indicate the locations of Figures 110 and 111.

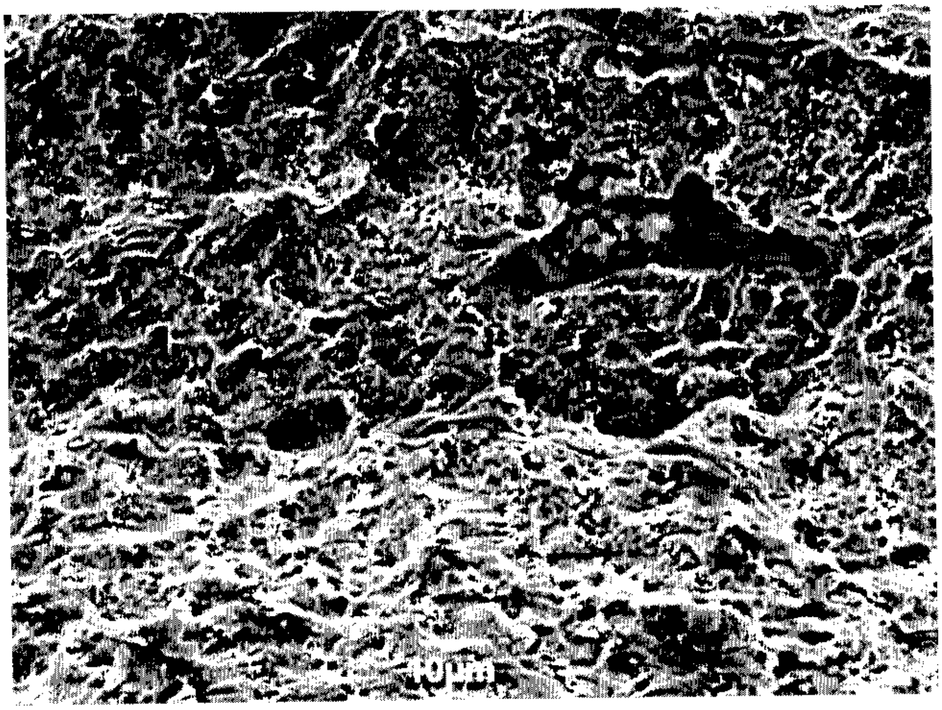


Figure 110 Joint No. 332 1000X

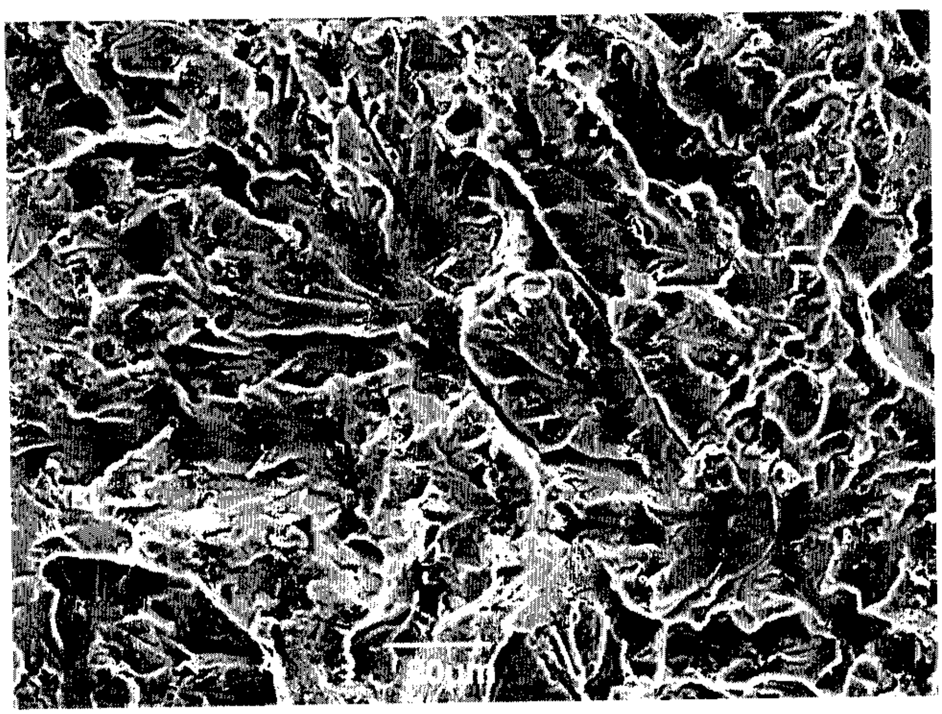


Figure 111 Joint No. 332 750X

Figure 110 shows the area in the box at top and Figure 111 shows the area in the lower box in Figure 109 at higher magnification.

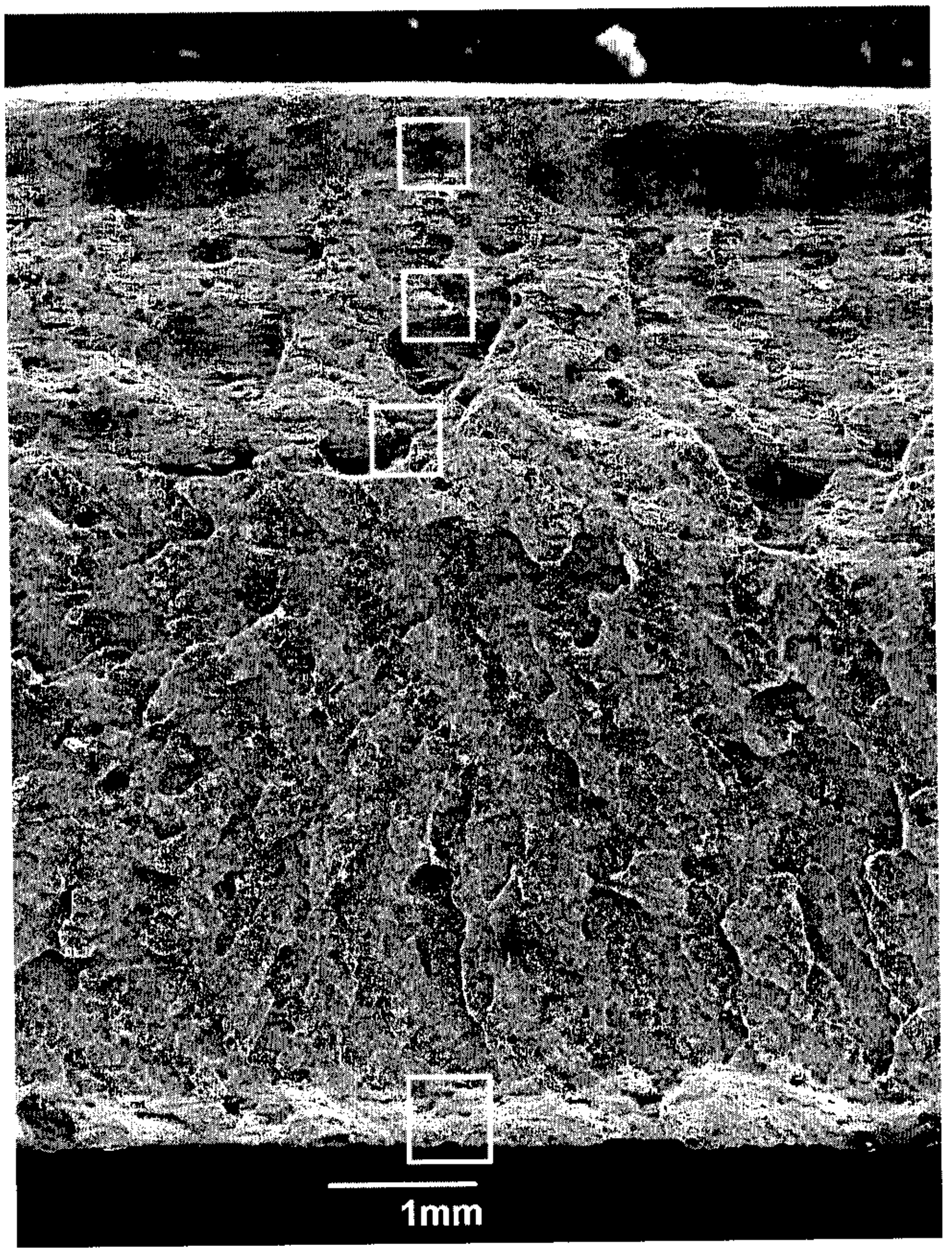


Figure 112 Joint No. 332 18X

Macrograph of the area to the right of the failure origin in Joint No. 332.

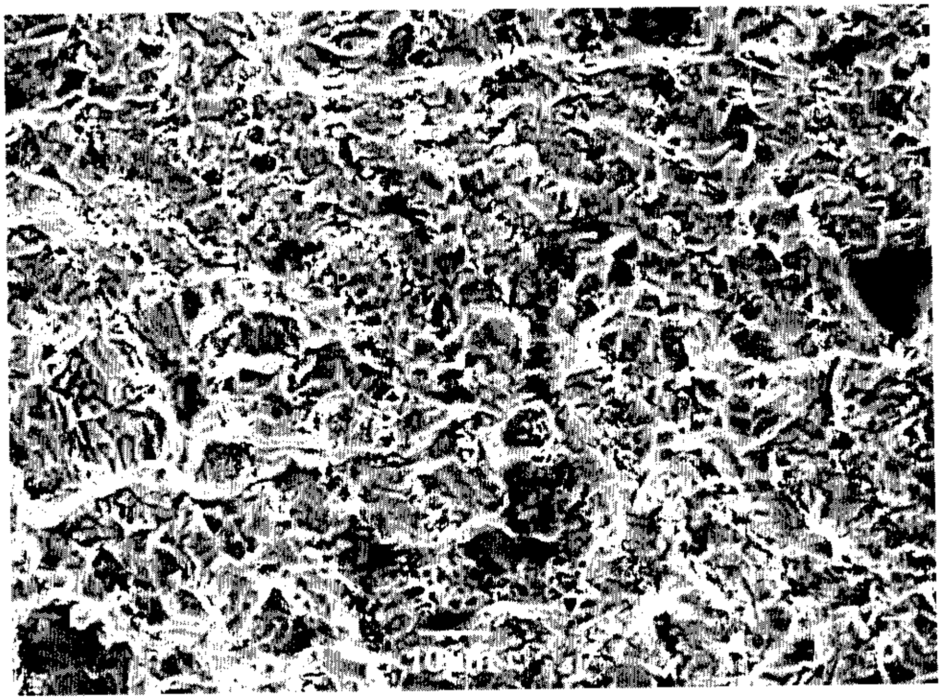


Figure 113 Joint No. 332 1000X

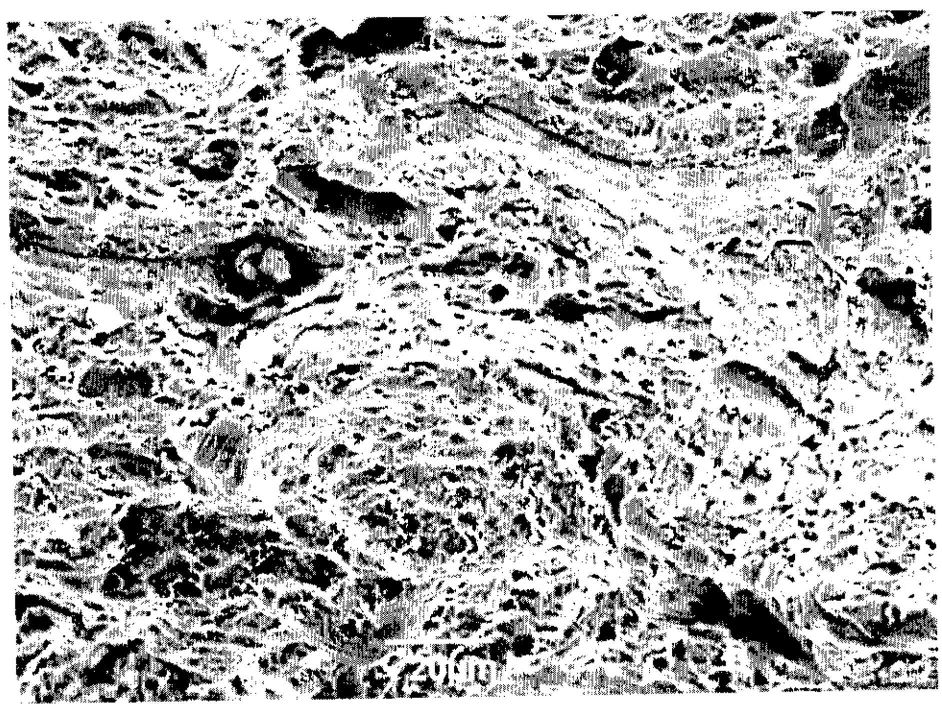


Figure 114 Joint No. 332 750X

Figure 113 shows the area in the box at top, and Figure 114 shows the area in the box at bottom in Figure 112.

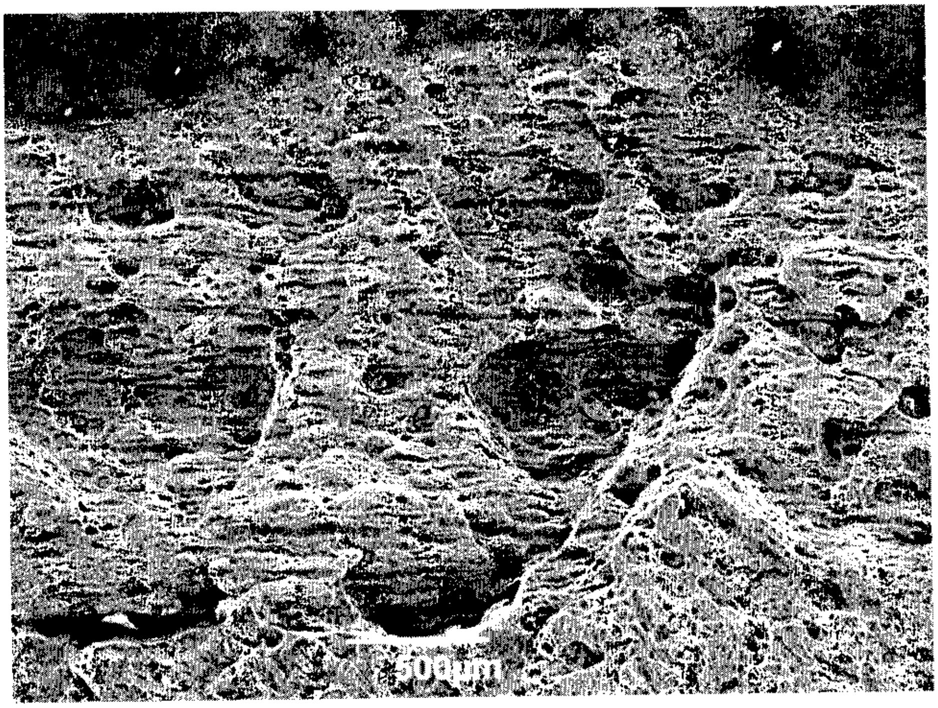


Figure 115 Joint No. 332 40X

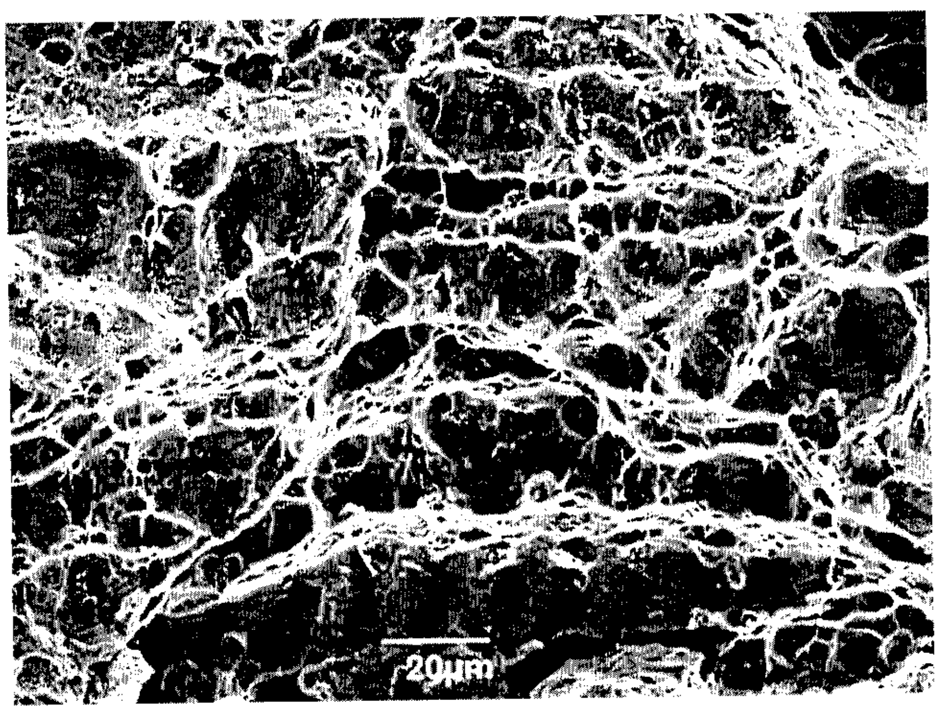


Figure 116 Joint No. 332 750X

Figure 115 shows a large area of woody fracture, and Figure 116 shows a typical location at higher magnification.

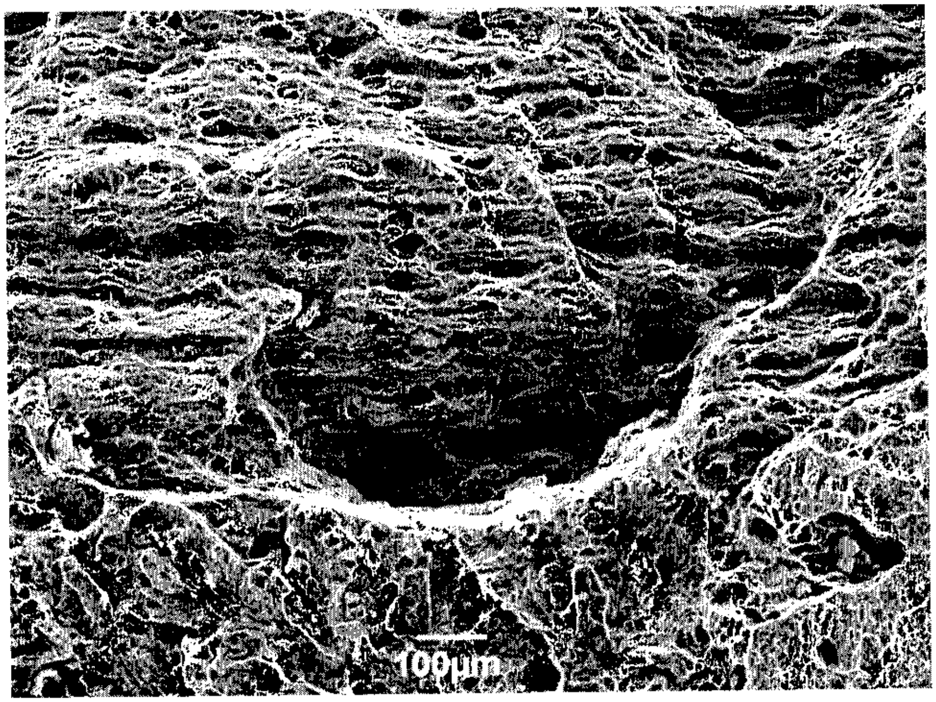


Figure 117 Joint No. 332 1000X

Transition from woody fracture, at top, to cleavage fracture at bottom.

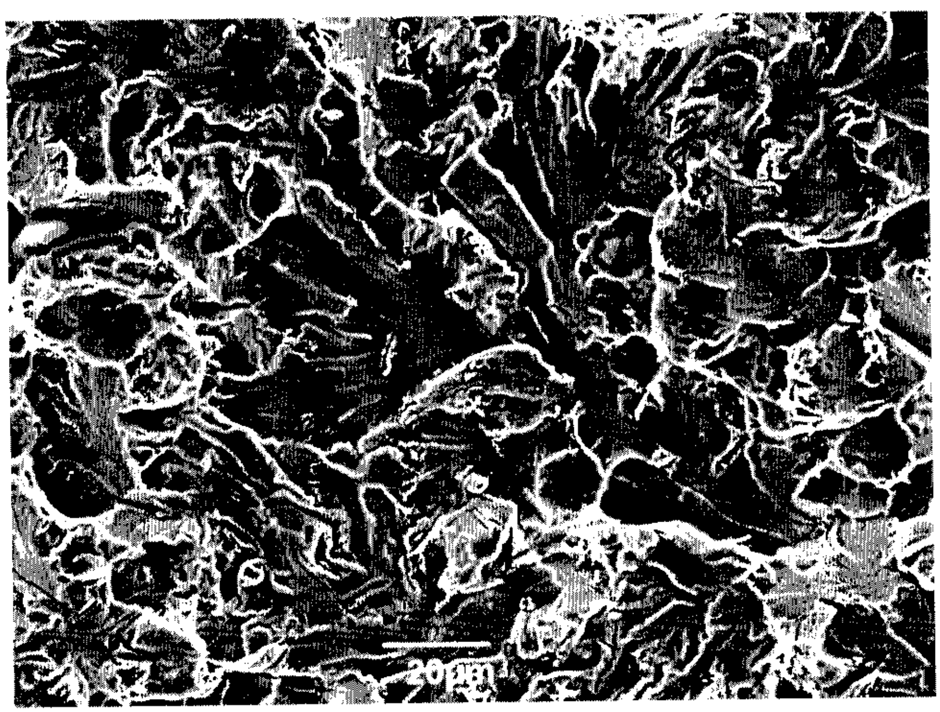


Figure 118 Joint No. 332 750X

View at higher magnification of the cleavage fracture.

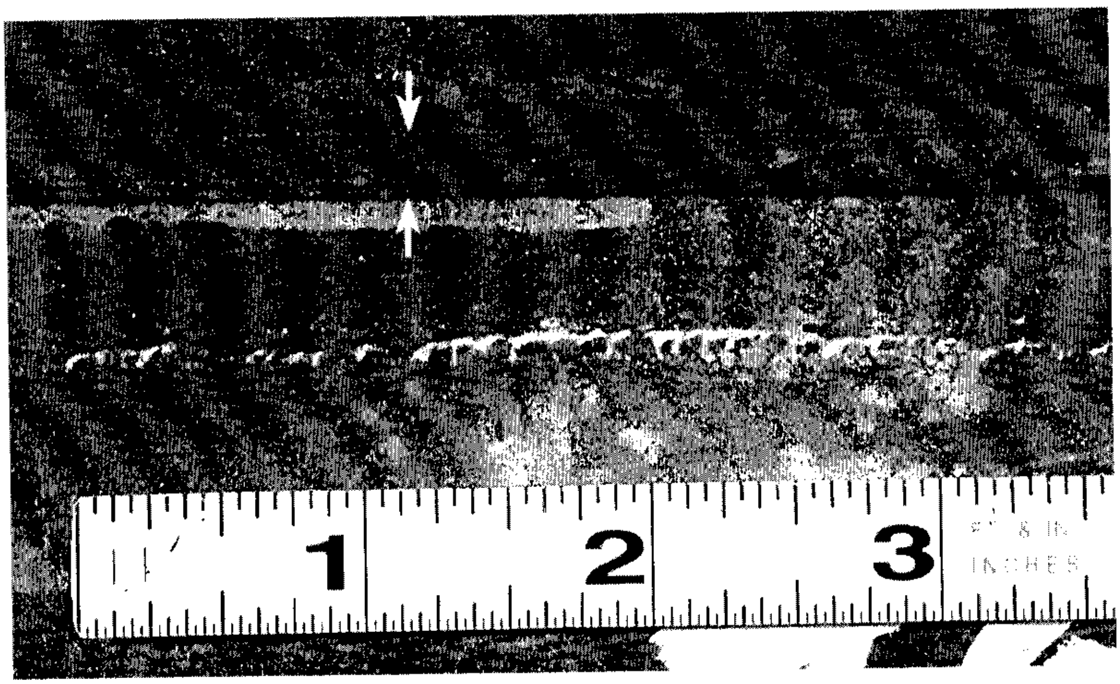
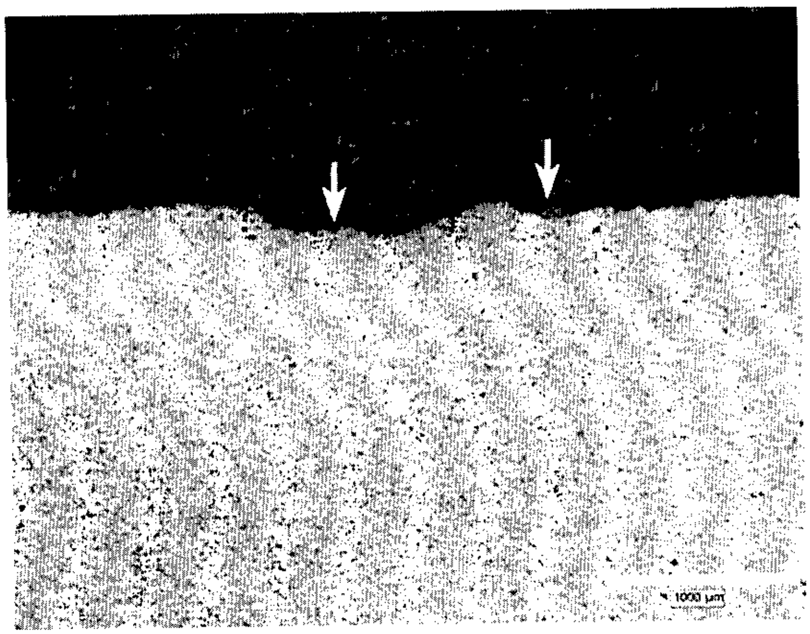


Figure 119 <u>Joint No. 6418</u>

Typical magnetic particle indications found adjacent to the weld of Joint No. 6418. The arrows indicate a shallow groove and tool marks from flash trimming.



Joint No. 6418

25X
Nital Etch

Figure 120

Photomicrograph showing a slight depression, arrow at left, and a small area of melted and re-solidified metal, arrow at right.

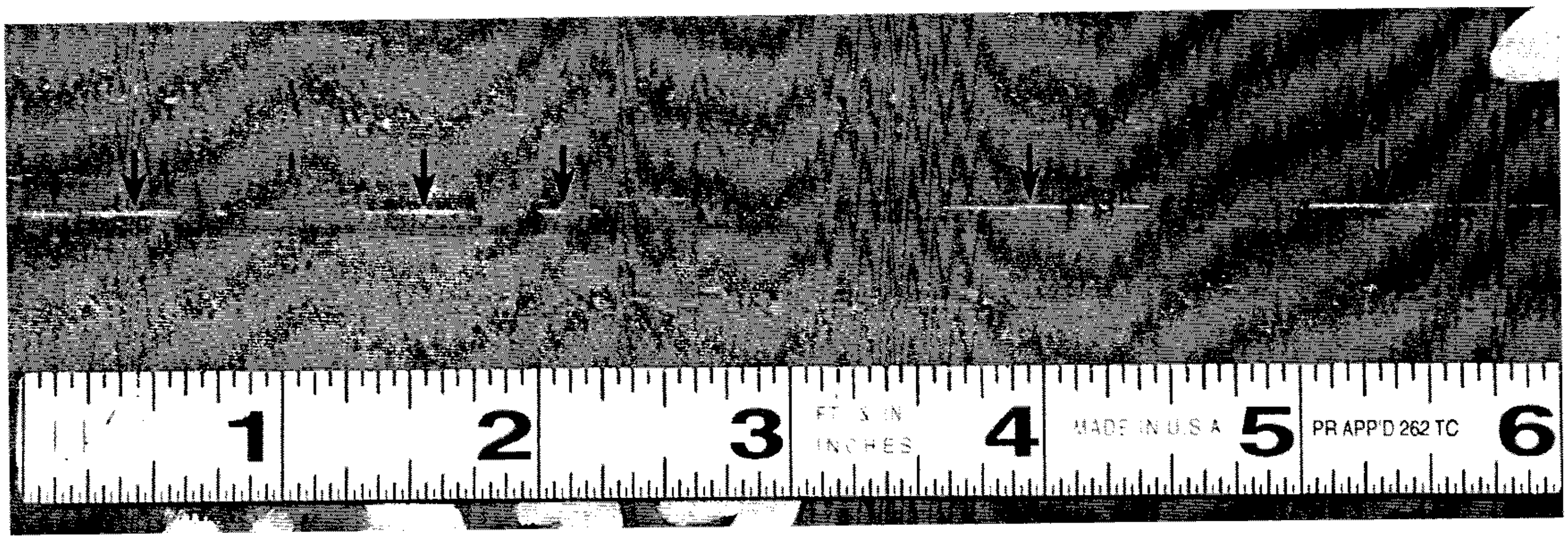
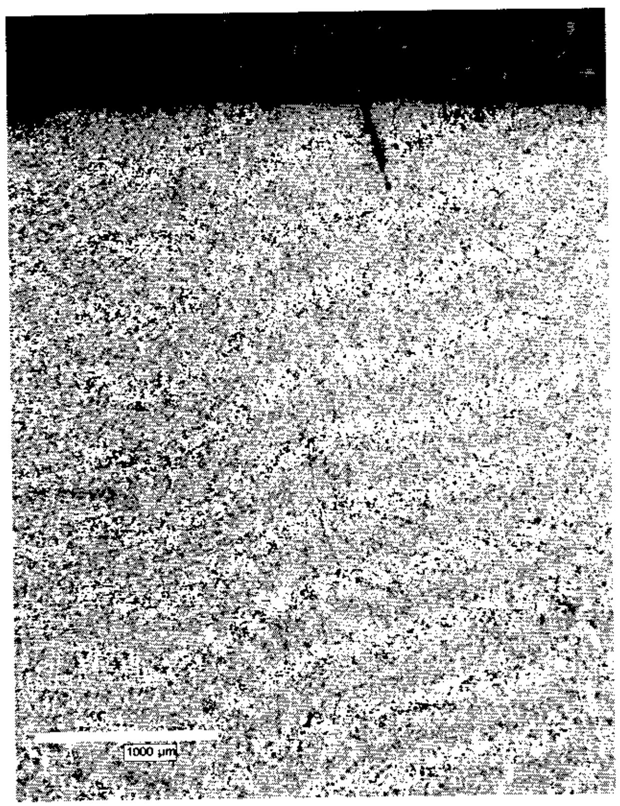


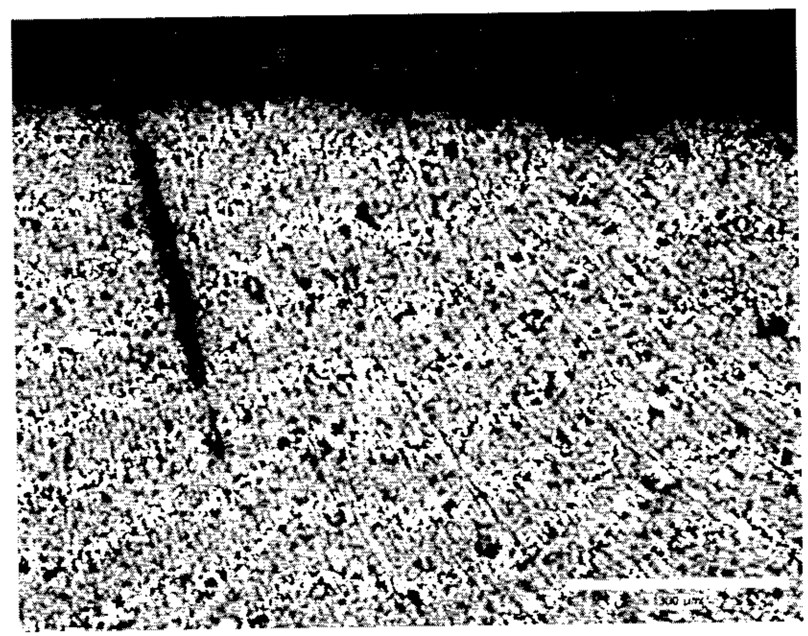
Figure 121

Joint No. 10737

Photograph of typical magnetic particle indications, arrows, on Joint No. 10737.



Joint No. 10737 25X
Nital Etch
Figure 122



Joint No. 10737 100X
Nital Etch
Figure 123

Views at two magnifications of a transverse section across one of the magnetic particle indications shown in Figure 121.

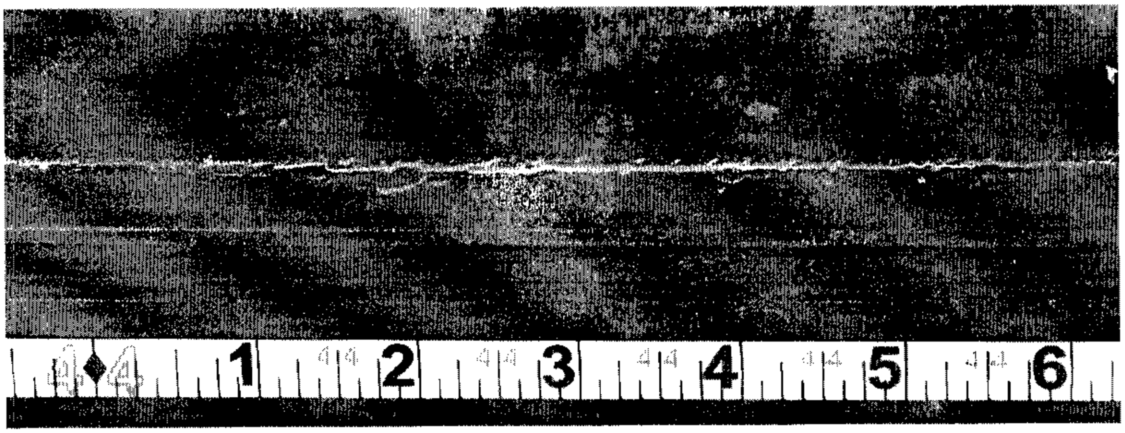
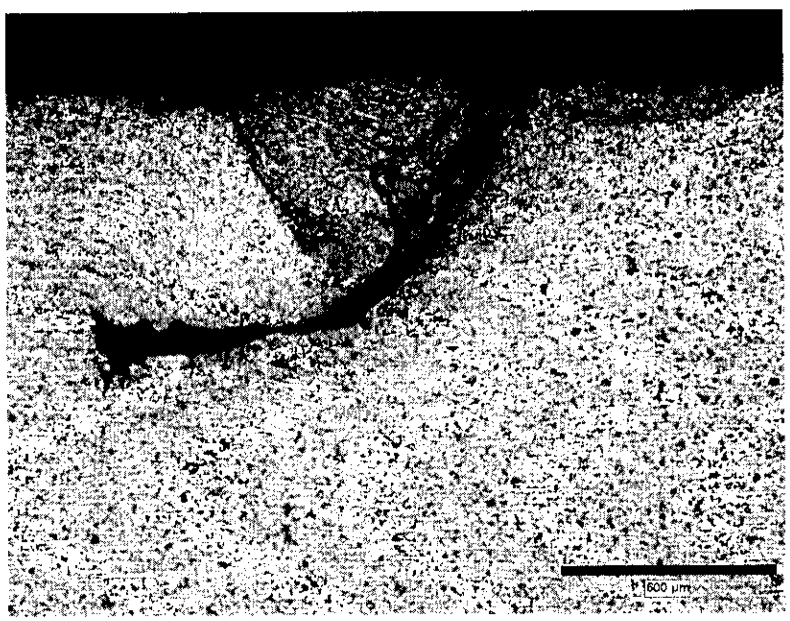


Figure 124 Joint No. 6418

Magnetic particle indications found on Joint No. 6418 after the fatigue test.



Joint No. 6418 50X

Figure 125 Nital Etch

Photomicrograph of a seam, black arrow, and contact mark, white arrow, at the magnetic particle indication.

Figure 126 Joint No. 10737

Photograph of the rupture in the fatigue test section from Joint No. 10737.

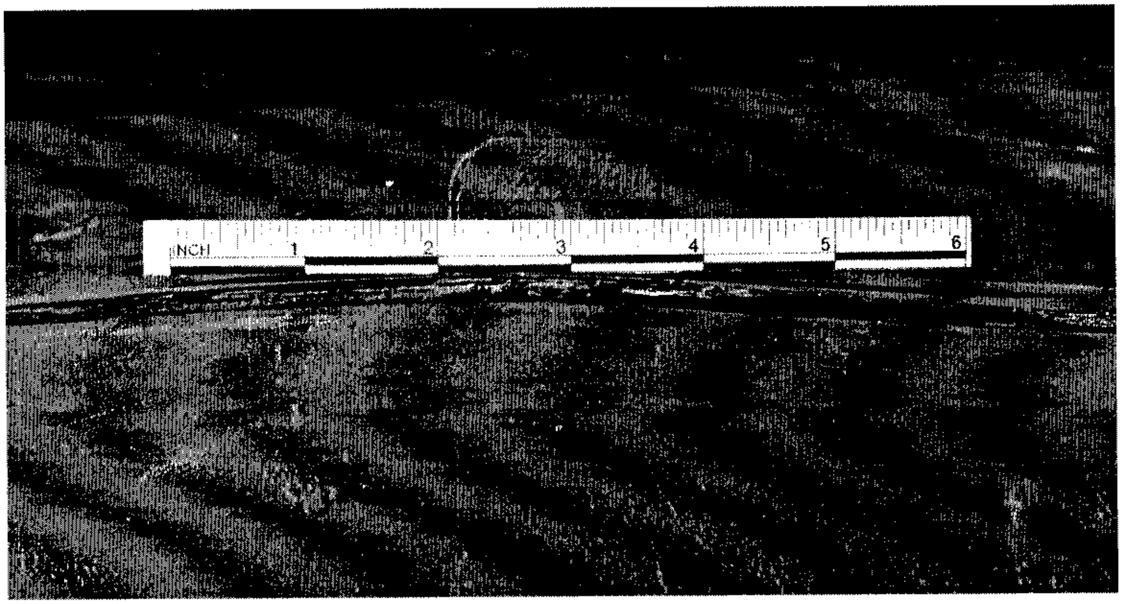


Figure 127 <u>Joint No. 10737</u>

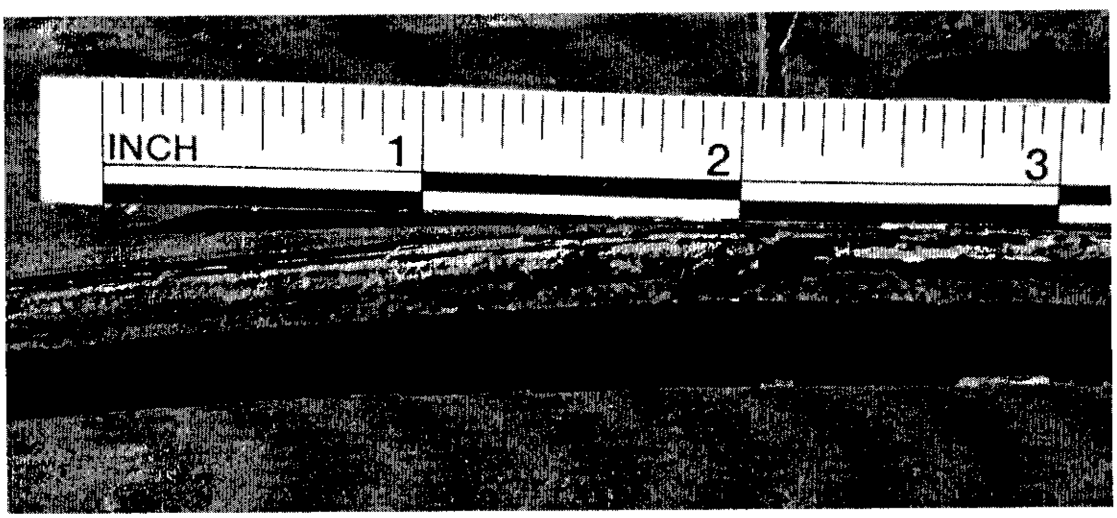


Figure 128 <u>Joint No. 10737</u>

Closer views of the fracture at the middle of the rupture.

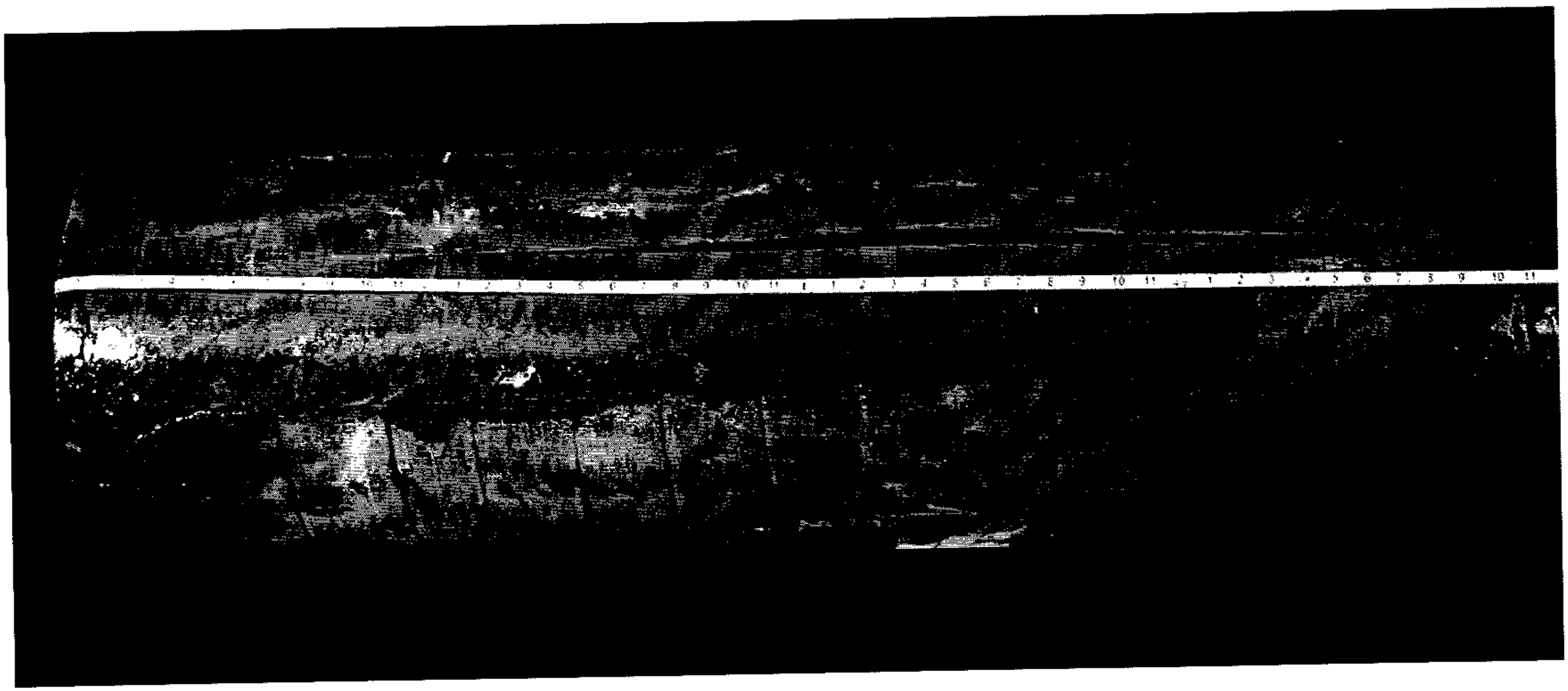


Figure 129 **Joint No. 10737**

Photograph of the fatigue fracture in Joint No. 10737, with the upstream end at right.

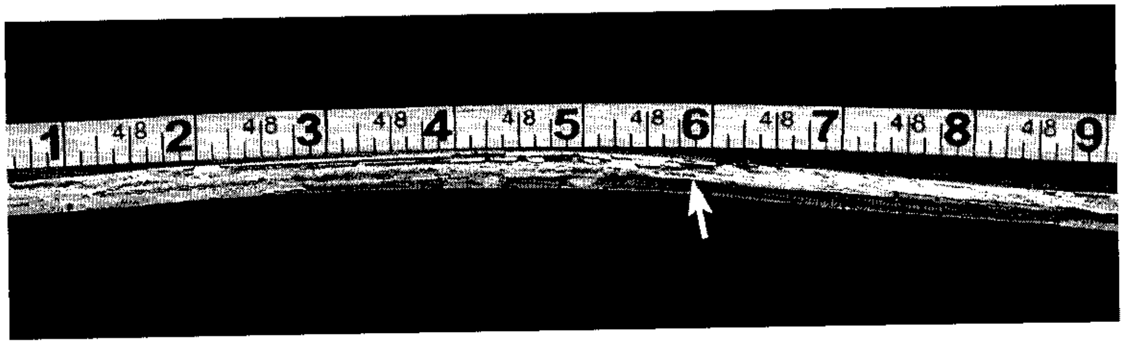


Figure 130 Joint No. 10737

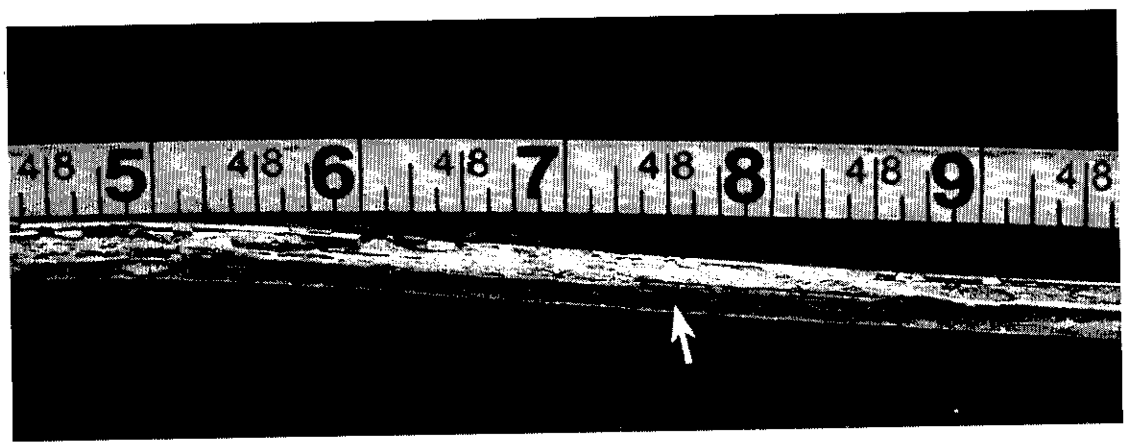


Figure 131 Joint No. 10737

Two views of the hook crack, arrows, near the middle of the rupture.

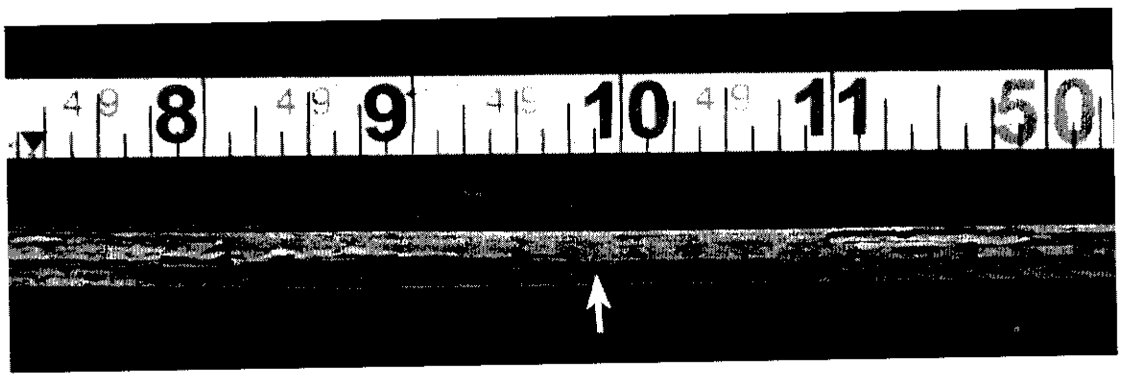


Figure 132 Joint No. 10737

Photograph of the hook crack near the downstream end of the rupture, arrow.

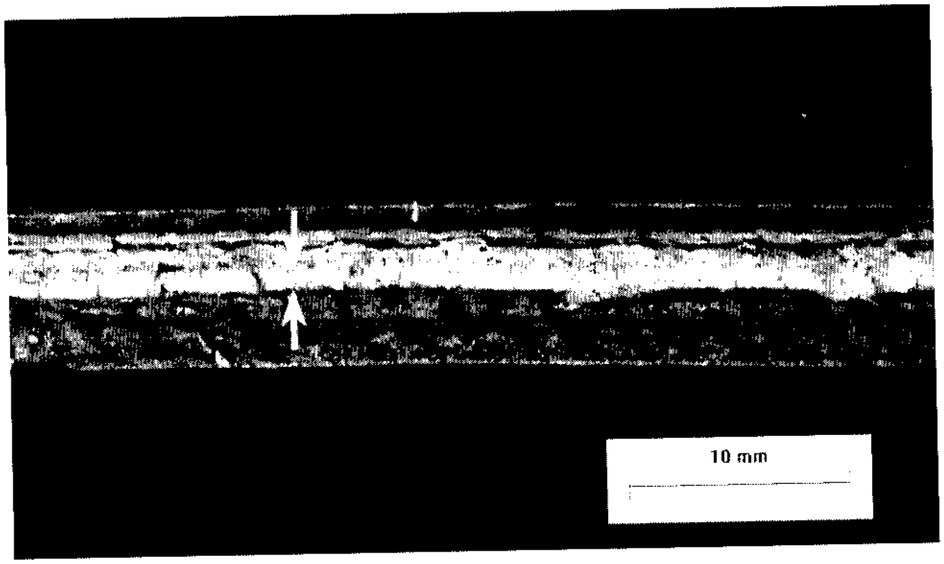


Figure 133 Joint No. 10737 3X

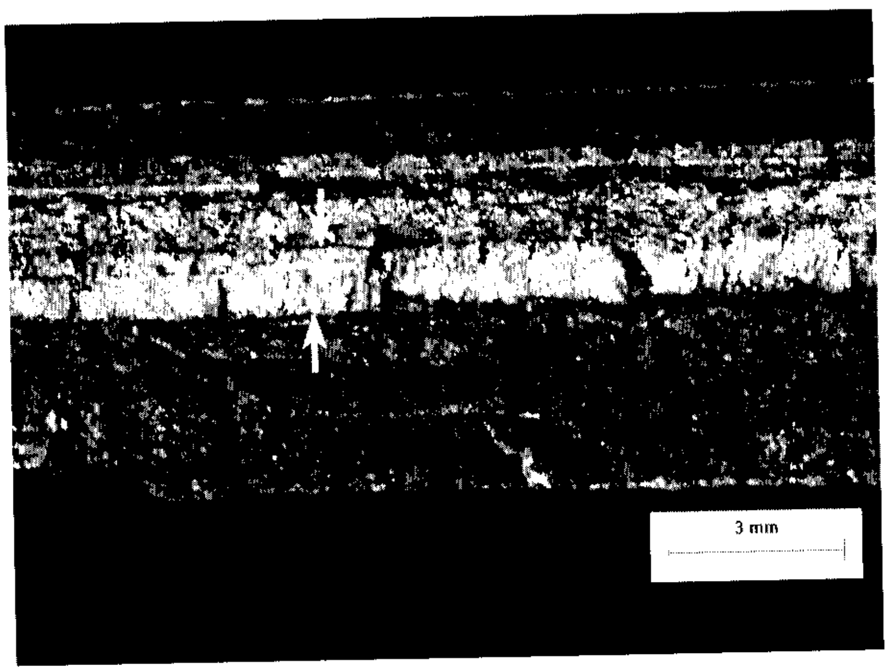


Figure 134 Joint No. 10737 8X

Close-up views of part of the fracture with suspected fatigue markings, between arrows.

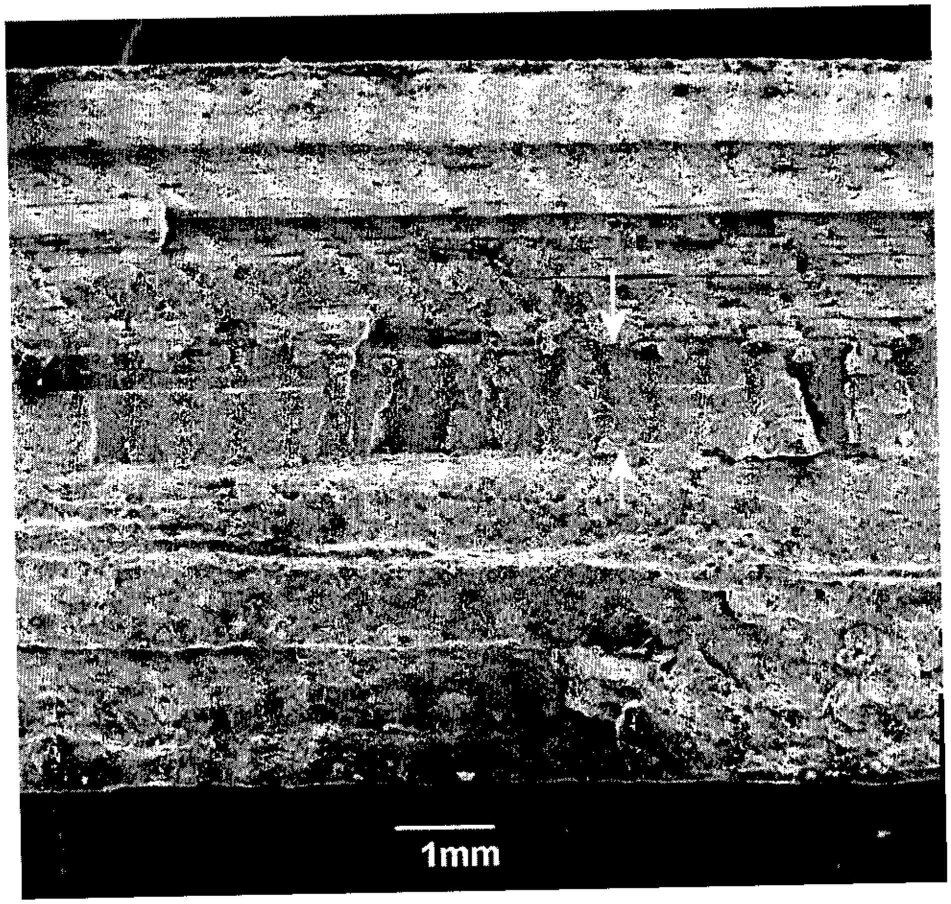


Figure 135 Joint No. 10737 15X

Electron micrograph with arrows indicating the band with possible fatigue markings.

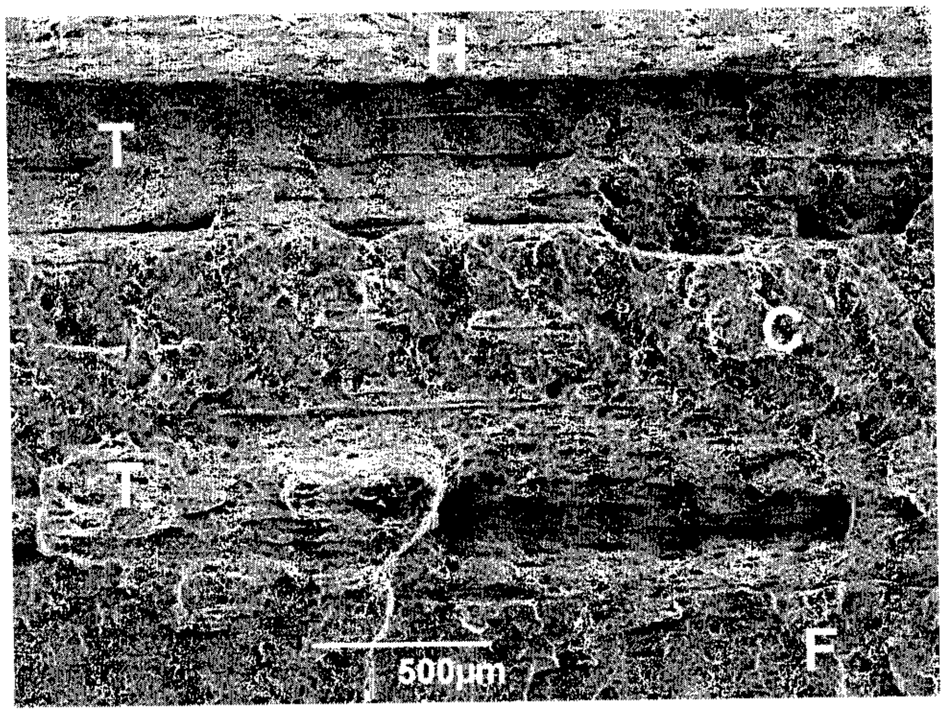


Figure 136 Joint No. 10737 50X

Electron micrograph of the fracture toward the outside surface. The letters indicate features shown in subsequent figures.

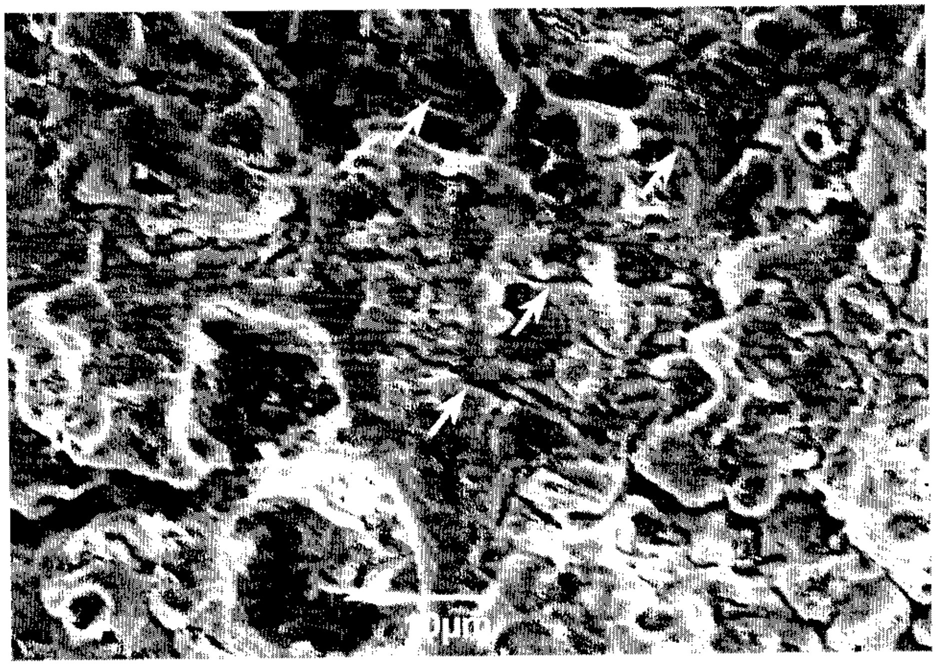


Figure 137 Joint No. 10737 2000X

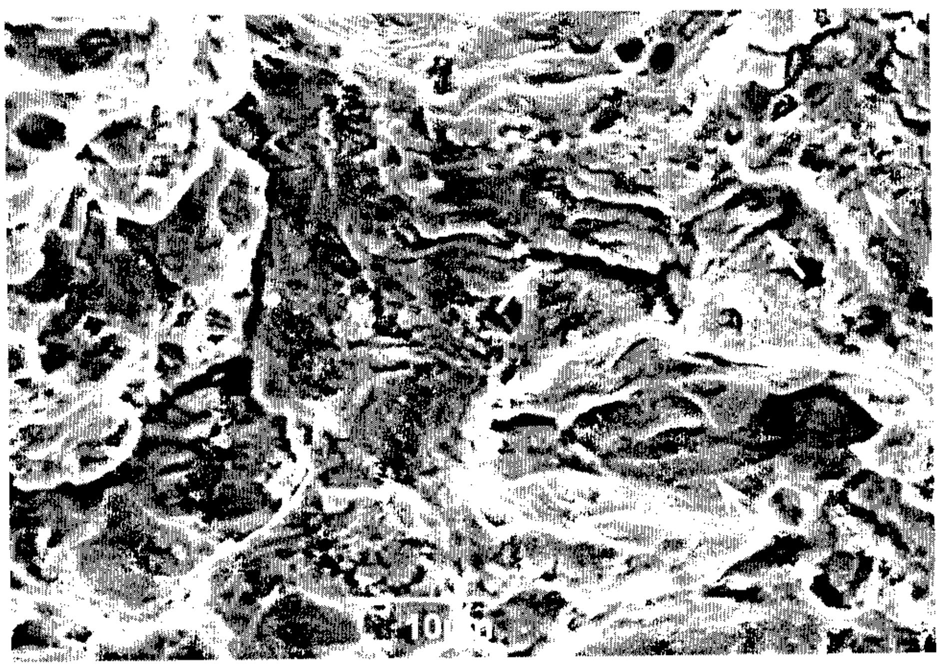


Figure 138 Joint No. 10737 2000X

Views at high magnification of fatigue indications, some of which are indicated by arrows, at two locations within the band indicated by the arrows in Figure 135.

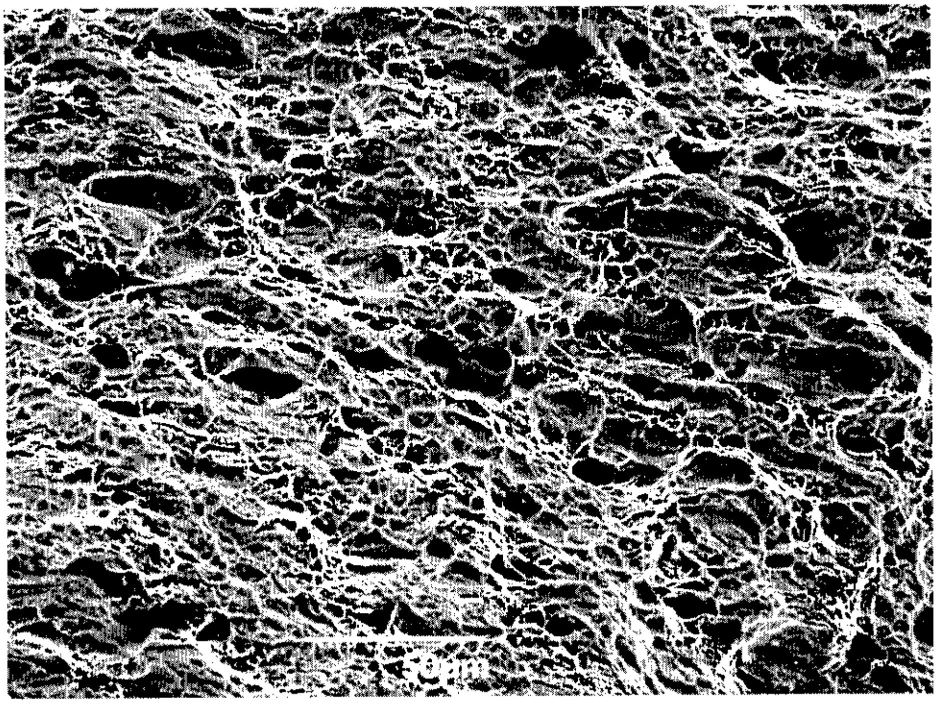


Figure 139 Joint No. 10737 500X

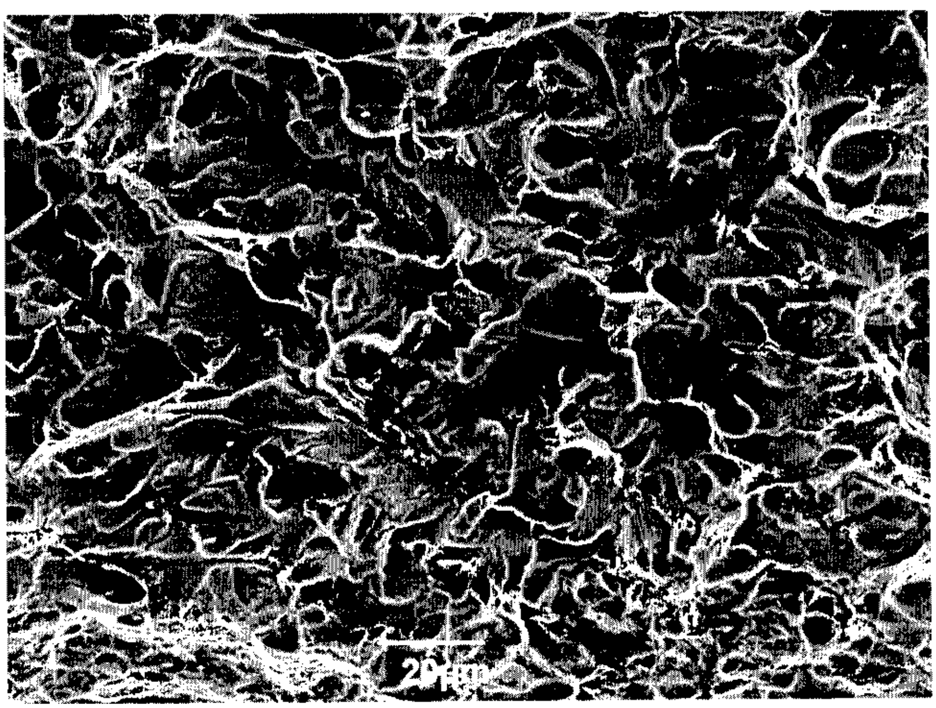
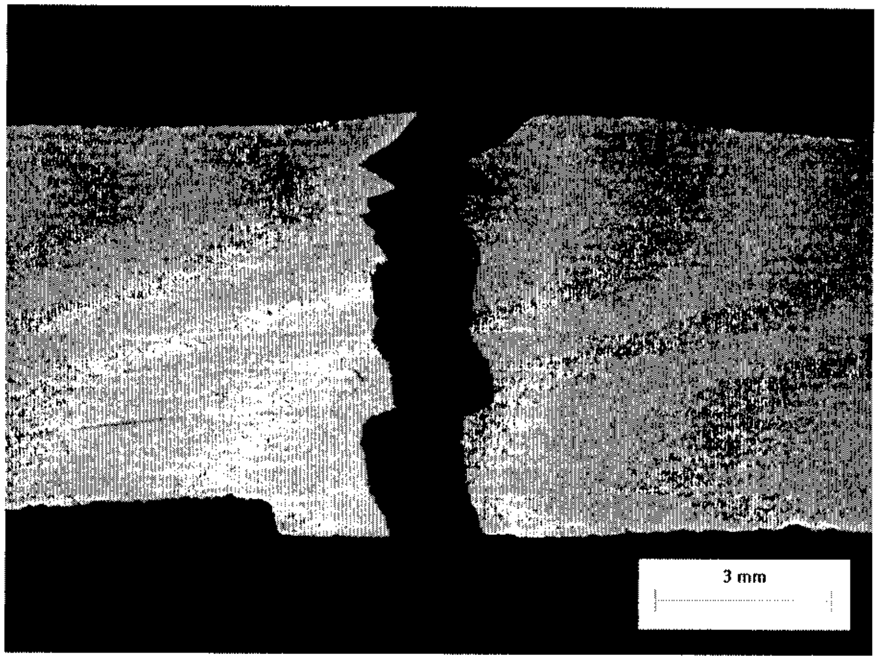


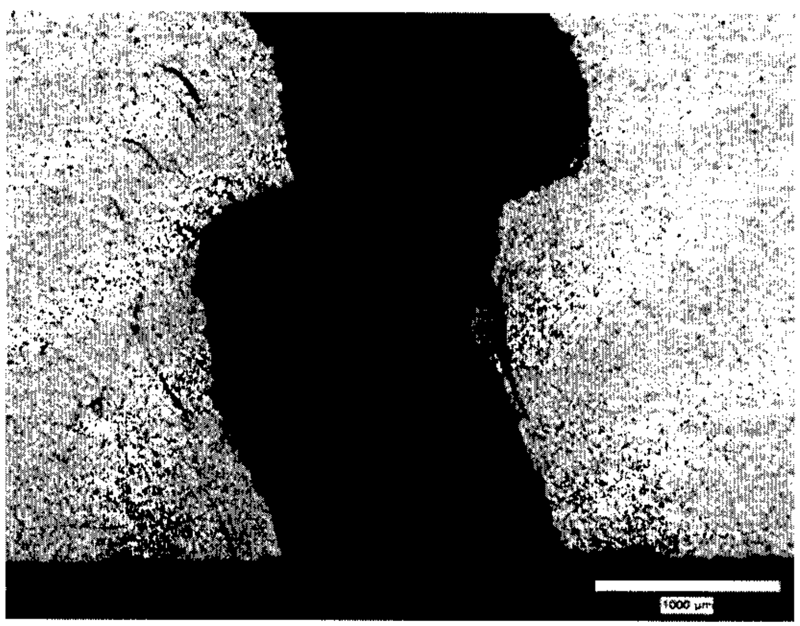
Figure 140 Joint No. 10737 750X

Figures 139 and 140 show representative areas of tearing and cleavage, respectively.



Joint No. 10737 8X
Figure 141 Nital Etch

Matching transverse sections from the middle of the fracture shown in Figure 134.



Joint No. 10737 25X
Figure 142 Nital Etch

View of the hook crack at the inside surface.

Figure 143 Joint No. 10737 50X

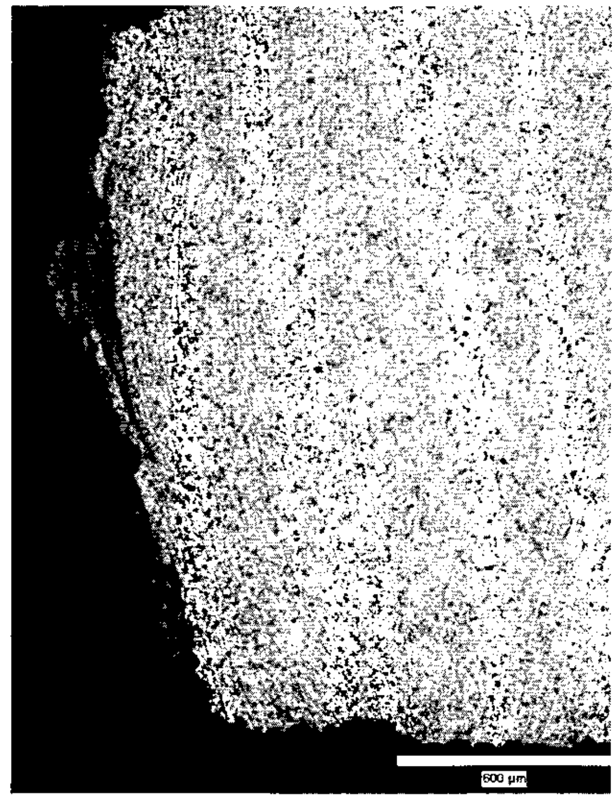
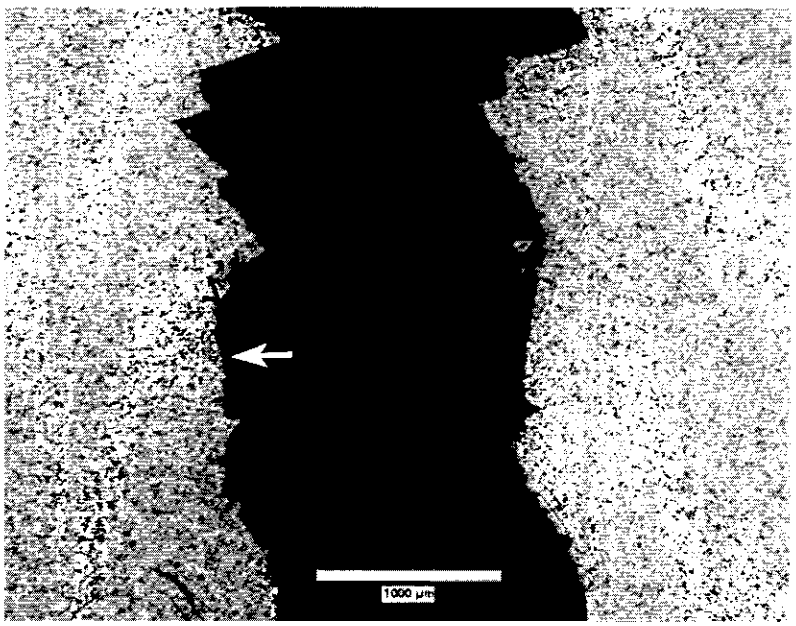
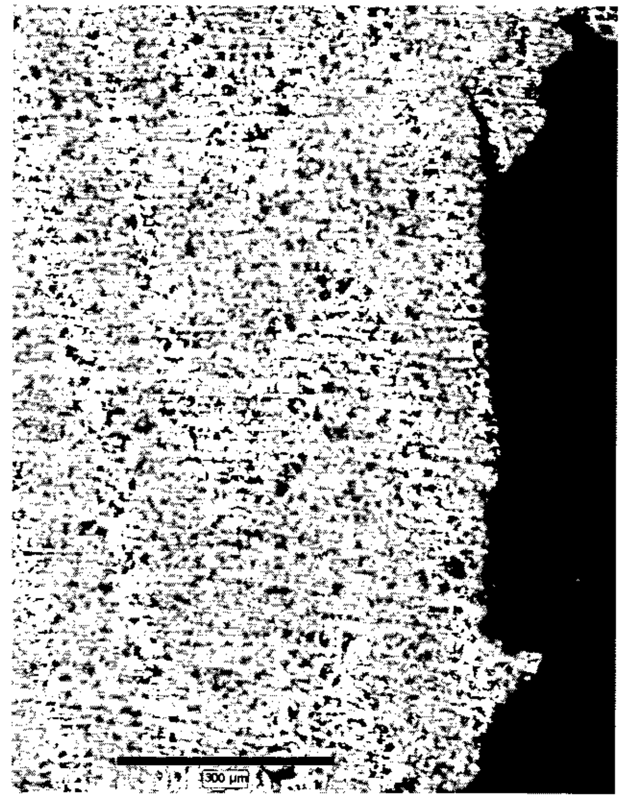


Figure 144 Joint No. 10737 50X

Views of the hook crack at higher magnification. Note the irregular fiber lines in Figure 143.



Joint No. 10737 25X
Figure 145 Nital Etch



Joint No. 10737 100X
Figure 146 Nital Etch

Figure 145 shows the fracture near midwall with an arrow indicating the flat fracture examined in the SEM, and Figure 146 shows the flat fracture at higher magnification.

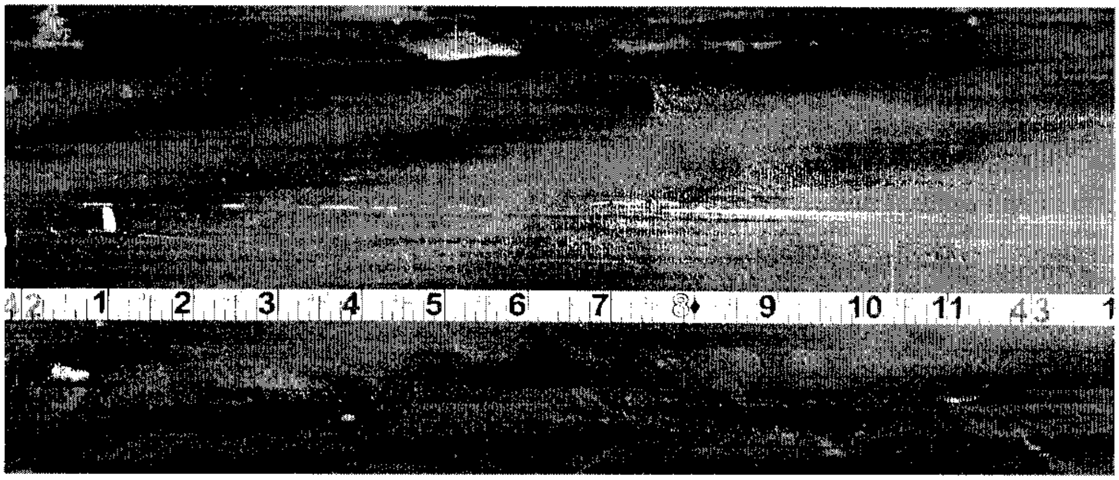


Figure 147 Joint No. 1037

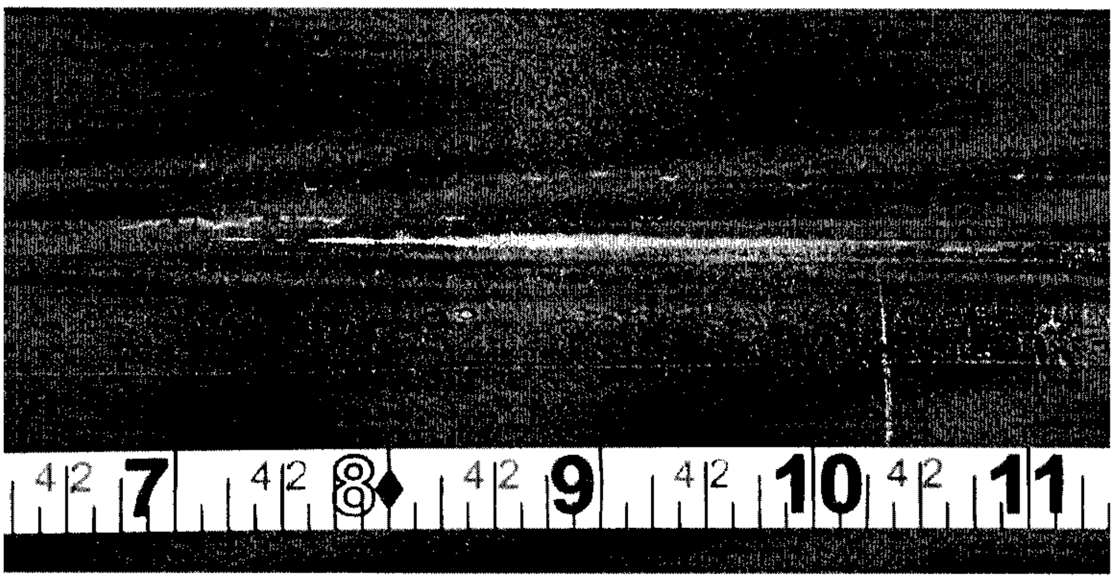
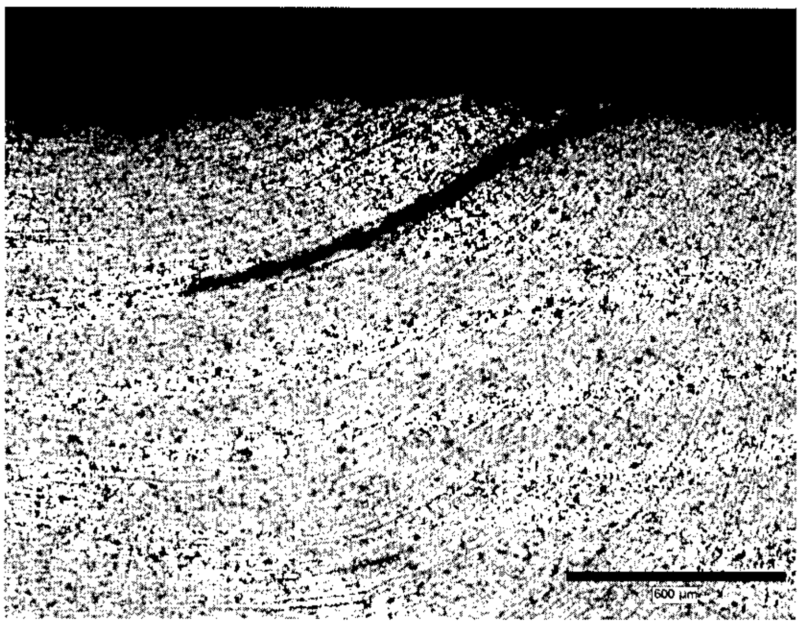


Figure 148 Joint No. 1037

Figure 147 shows magnetic particle indications along the fatigue-test section of Joint 1037 down stream from the rupture, and Figure 148 shows the heaviest magnetic particle build up.



Joint No. 1037 50X

Figure 149 Nital Etch

Section taken from the magnetic particle indication shown in Figure 148, showing that the indication was caused by a hook crack.

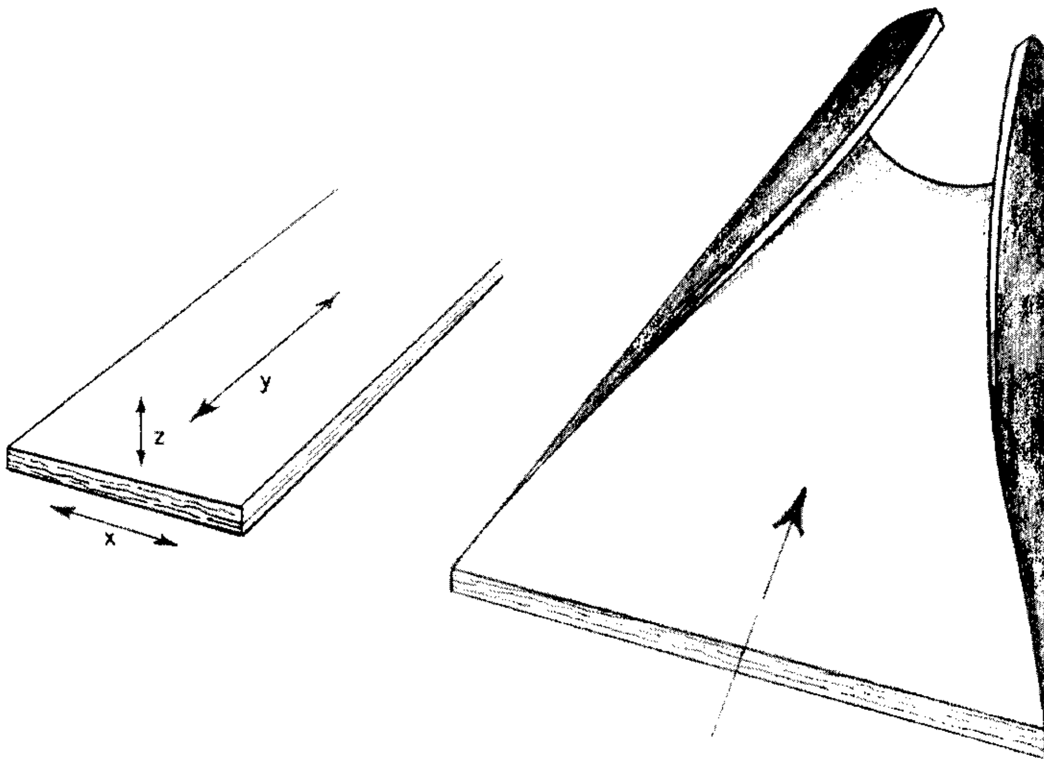


Figure 150

Schematic illustration of the fiber lines in skelp.

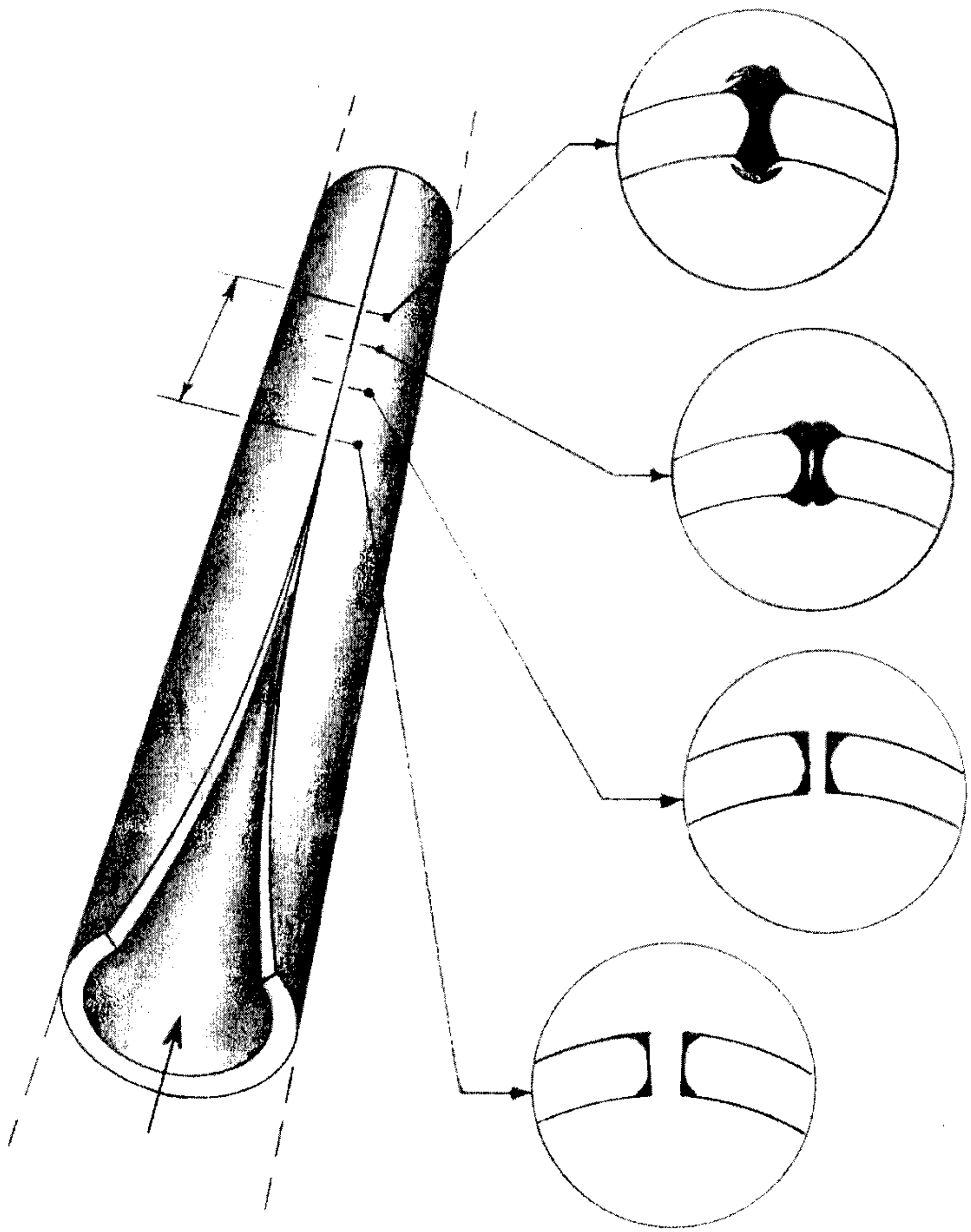


Figure 151

Schematic illustration of electric-resistance welding.

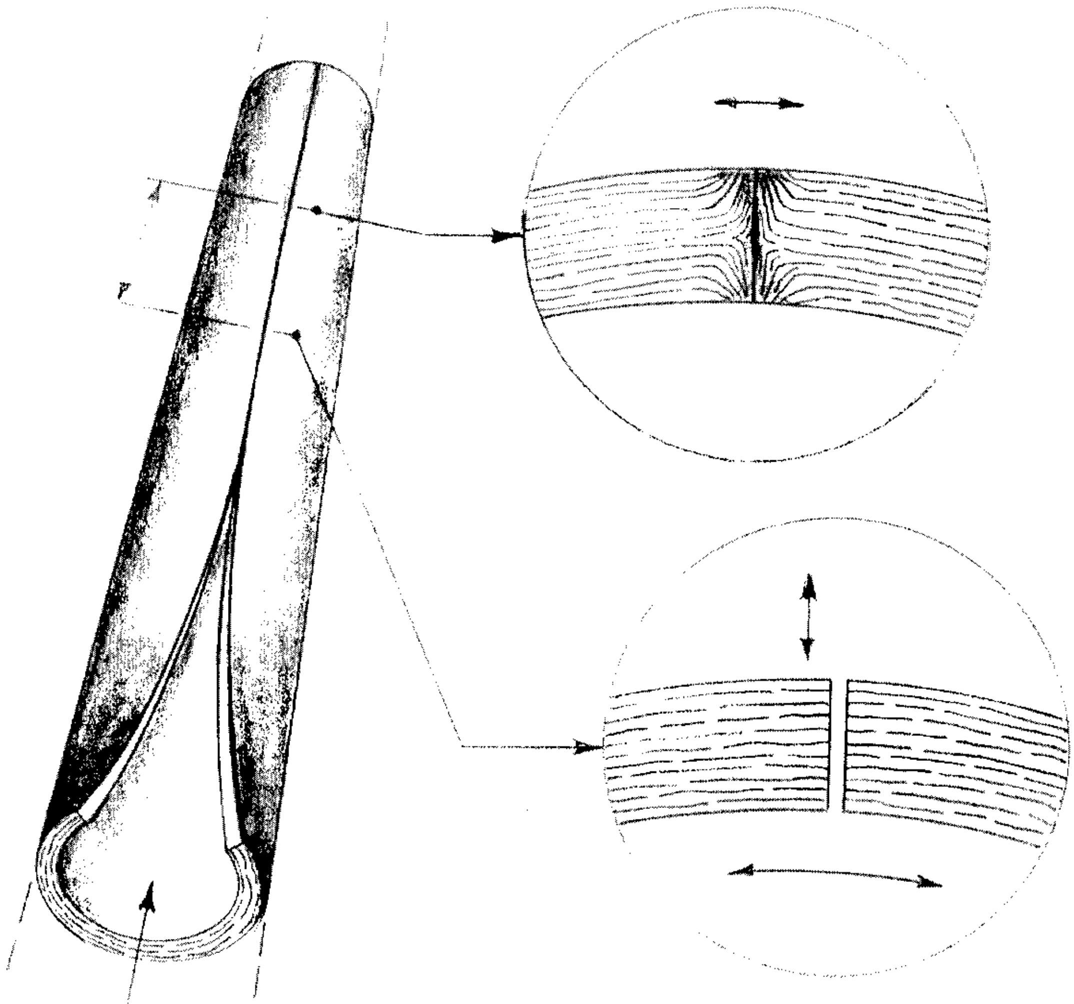


Figure 152

Schematic illustration showing how the fiber lines are bent at the weld.

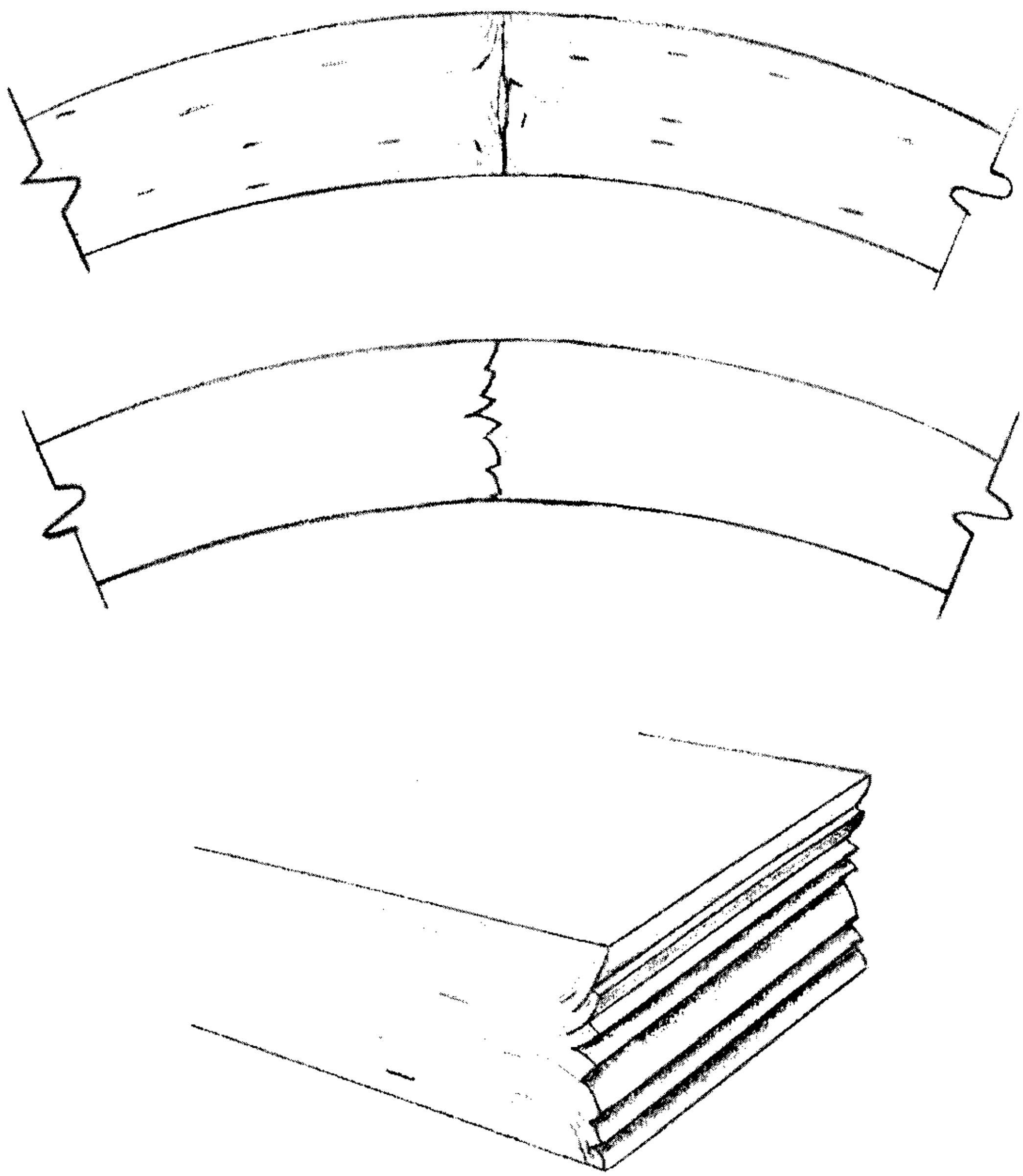


Figure 153

Schematic illustration of hook cracks across the wall thickness.

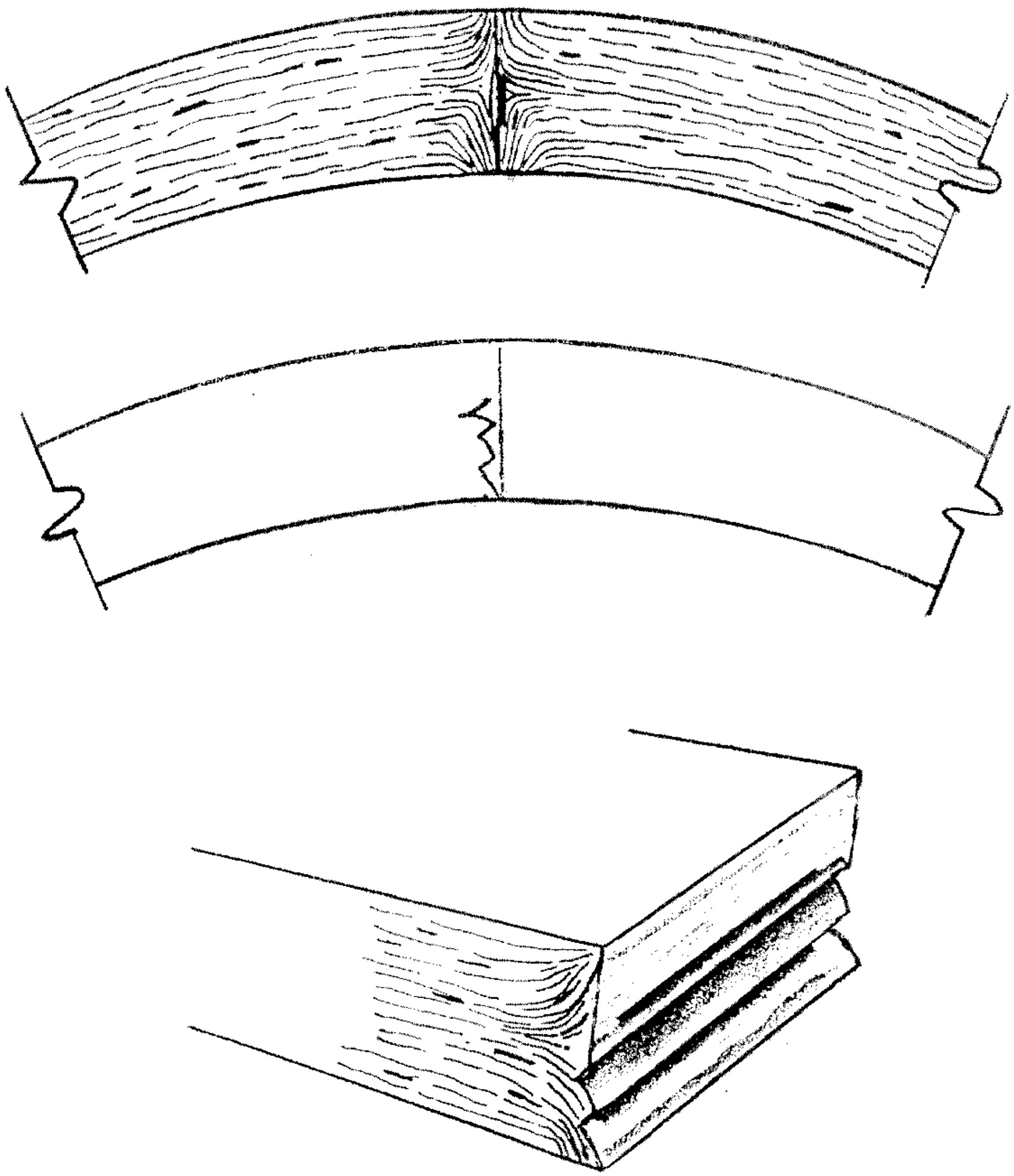


Figure 154

Schematic illustration of hook cracks at the inside surface with flat fracture above.

APPENDIX

Inspection Summary

No.	Area No.	Pipe No.	Inspection type	DuGW [ft]	Distance [ft]	Length [in]	Est. Depth [%WT]	Rel. Pos.	Rad. Pos.	Type	Lr	Kr	Pass/ Fail	Ranking	MP	Distance from US Pump Station (mi)	US Pump Station
6	LIN-01	324	Manual	0.0	16057.87	162.00	36.8%	IW	Ext	Crack	0.934	0.616	Pass		162.00	0.096	
7	LIN-02	332	Manual	19.0	16496.32	19.00	40.8%	AW	Ext	Crack	1.032	0.684	Fail	139	370.61	3.114	HA
8	LIN-03	332	Manual	20.2	16497.48	7.00	41.6%	AW	Ext	Crack	1.003	0.687	Fail	190	370.61	3.115	HA
9	LIN-04	332	Manual	21.0	16498.28	12.00	43.6%	AW	Ext	Cracks	1.079	0.772	Fail	24	370.61	3.115	HA
27	0004-01274	386	USCD	37.55	19478.26	16.10	25-40	aw	nd	nl	1.141	0.719	Fail	8	371.18	3.679	HA
83	0027-01119	2405	USCD	8.15	128524.52	540.30	25-40	aw	e	cl	1.029	0.683	Fail	152	391.83	24.332	HA
84	0027-00109	2405	USCD	49.24	128565.61	20.60	25-40	aw	e	cl	1.029	0.671	Fail	172	391.84	24.340	HA
97	0030-01025	2753	USCD	23.17	146769.72	6.00	25-40	aw	nd	cl	1.080	0.676	Fail	98	395.29	27.787	HA
98	0030-01034	2753	USCD	32.32	146778.88	4.90	25-40	aw	nd	cl	1.052	0.662	Fail	131	395.29	27.789	HA
99	0030-01041	2753	USCD	39.30	146785.85	12.40	25-40	aw	nd	cl	1.141	0.711	Fail	12	395.29	27.790	HA
100	0030-01046	2753	USCD	42.32	146788.87	24.50	25-40	aw	nd	cl	1.141	0.727	Fail	6	395.29	27.791	HA
105	0031-00297	2796	USCD	24.85	149107.62	107.80	25-40	aw	e	cl	1.074	0.698	Fail	79	395.73	28.230	HA
106	0031-00303	2796	USCD	37.77	149120.54	28.20	25-40	aw	e	cl	1.074	0.691	Fail	93	395.73	28.233	HA
107	0031-00312	2797	USCD	12.30	149146.42	40.30	25-40	aw	e	cl	1.074	0.694	Fail	88	395.74	28.237	HA
142	0040-00553	3645	USCD	31.53	194819.07	3.10	>40	aw	e	cl			Fail	1	404.39	36.888	HA
143	0040-00955	3645	USCD	49.95	194837.48	6.70	25-40	aw	e	cl	1.032	0.662	Fail	177	404.39	36.891	HA
150	0042-01001	3897	USCD	5.90	206369.68	323.40	25-40	aw	e	cl	1.123	0.717	Fail	19	406.58	0.375	YC
158	0044-00278	4013	USCD	45.60	212784.26	8.30	25-40	aw	i	cl	1.119	0.695	Fail	32	407.79	1.590	YC
199	5	5204	PAUT	8.9	276313.33	3.43	49.2%	AW	Ext	Crack	0.940	0.780	Fail	182	419.82	13.622	YC
200	LIN-05	5204	Manual	20.5	276324.50	11.00	41.6%	AW	Ext	LOF	1.017	0.671	Fail	186	419.82	13.624	YC
201	LIN-07	5204	Manual	27.2	276331.65	4.75	39.2%	AW	Ext	LOF	0.919	0.602	Pass		4.75	0.105	
202	52	5204	PAUT	45.9	276350.14	7.53	40.0%	IW/AW	Ext	LOF & Crack	0.976	0.673	Fail	220	419.83	13.629	YC
234	0019-00536	6005	USCD	50.865	319920.16	32.20	25-40	iw	e	cl	1.029	0.719	Fail	122	428.08	2.581	CR
238	0020-00609	6102	USCD	39.10	325078.61	16.70	25-40	aw	i	cl	1.096	0.704	Fail	37	429.06	3.558	CR
239	0020-00119	6105	USCD	13.86	325213.07	3.60	25-40	aw	i	nl	1.008	0.635	Fail	212	429.08	3.583	CR
240	0020-00169	6106	USCD	16.50	325271.88	15.00	25-40	aw	i	nl	1.141	0.717	Fail	9	429.09	3.595	CR
253	LIN-01	6418	Manual	41.0	342403.32	54.00	36.8%	AW	Ext	Crack	0.973	0.605	Pass		54.00	0.093	
254	2	6418	PAUT	41.4	342403.74	6.45	36.0%	AW	Ext	Crack	0.929	0.564	Pass		6.45	0.099	
255	7	6418	PAUT	44.0	342406.28	18.90	36.0%	AW	Ext	Crack	0.964	0.583	Pass		18.90	0.093	
271	LIN-01	6903	Manual	0.8	368987.49	67.00	36.0%	IW	Ext	LOF	0.905	0.584	Pass		67.00	0.099	
272	47	6903	PAUT	0.8	368987.52	13.50	40.0%	AW	Ext	Crack	1.015	0.652	Fail	199	437.37	11.874	CR
273	LIN-02	6903	Manual	6.8	368993.55	43.50	37.6%	IW	MW	LOF Int	1.047	0.700	Fail	118	437.38	11.875	CR
274	16	6903	PAUT	8.0	368994.70	24.05	67.6%	AW	Ext	Crack	1.587	2.015	Fail	2	437.38	11.875	CR
275	21	6903	PAUT	10.0	368996.71	4.20	44.0%	AW	Ext	Crack	0.935	0.698	Fail	253	437.38	11.876	CR
276	22	6903	PAUT	10.4	368997.09	7.50	40.0%	AW	Ext	Crack	0.982	0.637	Fail	244	437.38	11.876	CR
277	27	6903	PAUT	12.5	368999.23	18.05	49.2%	IW	Ext	Crack	1.153	1.024	Fail	4	437.38	11.876	CR
278	LIN-03	6903	Manual	13.0	368999.72	75.00	40.8%	IW	MW	LOF Int	1.080	0.763	Fail	28	437.38	11.876	CR
279	42	6903	PAUT	16.0	369002.72	23.98	36.0%	AW	Ext	Crack	0.964	0.586	Pass		23.98	0.093	
280	43	6903	PAUT	18.0	369004.70	18.30	38.0%	AW	Ext	Crack	0.989	0.620	Fail	248	437.38	11.877	CR
281	45	6903	PAUT	21.8	369008.54	3.48	40.0%	AW	Ext	Crack	0.888	0.591	Pass		3.48	0.111	

No.	Area No.	Pipe No.	Inspection type	DuGW [ft]	Distance [ft]	Length [in]	Est. Depth [%WT]	Rel. Pos.	Rad. Pos.	Type	Lr	Kr	Pass/ Fail	Ranking	MP	Distance from US Pump Station (mi)	US Pump Station
322	0036-00804	7634	USCD	8.85	407088.45	26.00	25-40	aw	i	cl	1.096	0.713	Fail	34	444.59	0.790	BU
324	0038-00190	7757	USCD	20.40	413933.43	8.10	25-40	aw	nd	cl	1.117	0.693	Fail	33	445.89	2.086	BU
363	0049-00207	8769	USCD	27.53	468346.45	19.50	25-40	aw	i	nl	1.141	0.723	Fail	7	456.19	12.392	BU
396	3	10737	PAUT	5.0	572836.42	10.93	36.0%	IW	Ext	LOF	0.942	0.597	Pass		10.93	0.094	
397	14	10737	PAUT	6.4	572837.78	3.70	48.0%	IW	MW	LOF ID/OD/MW Stacked	0.989	0.778	Fail	119	475.98	32.182	BU
398	LIN-02	10737	Manual	6.6	572838.03	49.00	47.2%	IW	nt/Ext/MW	LOF	1.205	1.038	Fail	3	475.98	32.182	BU
399	15	10737	PAUT	8.0	572839.39	23.08	36.0%	IW	Int	LOF & Crack	1.002	0.643	Fail	214	475.98	32.182	BU
400	LIN-09	10737	Manual	29.8	572856.40	7.88	32.8%	IW	nt/Ext/MW	LOF	0.961	0.569	Pass		7.88	0.087	
401	LIN-07	10737	Manual	25.2	572856.59	6.75	38.0%	IW	nt/Ext/MW	LOF	0.989	0.645	Fail	228	475.99	32.186	BU
402	LIN-12	10737	Manual	39.9	572871.28	18.00	34.4%	IW	nt/Ext/MW	LOF	0.983	0.609	Fail	265	475.99	32.188	BU
403	65	10737	PAUT	42.0	572873.40	24.00	38.0%	IW	Ext	LOF	0.965	0.645	Fail	262	475.99	32.189	BU
404	LIN-13	10737	Manual	42.6	572873.99	41.00	32.8%	IW	nt/Ext/MW	LOF	0.959	0.582	Pass		41.00	0.086	
405	LIN-14	10737	Manual	46.6	572877.98	49.00	44.8%	IW	nt/Ext/MW	LOF	1.127	0.895	Fail	5	475.99	32.190	BU
406	LIN-15	10737	Manual	51.9	572883.27	68.00	37.2%	IW	nt/Ext/MW	LOF	1.030	0.686	Fail	141	475.99	32.191	BU